F.Yu. ZIEGEL

WONDERS OF THE NIGHT SKY

This is a book about astronomical observations of the night sky. At an elementary level it tells about unusual stars, star clusters and nebulae. There are stories of how the constellations originated, and the sights of each one are explained. In short, this is a beginner's guide to the constellations. It is an observational guide so that reading the text should always be accompanied by night-time observations of the starry sky.

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WHY KNOW THE CONSTELLATIONS

The night sky is a great book of nature filled with magnificent riches about the universe for those who learn to read it. The astronomically uninitiated cannot even begin to imagine the wealth of material forms and inexhaustible creativity of mother nature hidden in the tiny patterns of the sky which the ancients named constellations.

Over the centuries, people have marvelled and studied the starry sky—one of the most magnificent of all sights. Today, to use the words of Tsiolkovsky, we have entered an "era of careful study of the sky". Spaceflight has brought the stars closer, and now even those far removed from astronomy want to get the true meaning of this amazing spectacle.

The ABC's of astronomy begin with a knowledge of the constellations, which is important both to the ordinary lover of astronomy and to the specialist. Just as the geographer must know his globe, so the astronomer cannot allow himself to get lost in the stellar patterns of the night sky.

A person with a good knowledge of the constellations and their positions relative to the horizon at various times of the day and year is able to orient himself in unknown territory and even estimate the time. That was actually the reason why the ancients made such a close study of the night sky. Methods of orientation by the stars and constellations are still very important to tourists, scouts, and sailors and pilots—in short, to everyone for whom landmarks are not enough in their travels. And for observers of artificial earth satellites and space vehicles, a knowledge of the constellations is a must.

From the surface of the earth we see only half of the sky at one time. Astronauts on a lunar mission will have quite a different picture. The landscapes of the earth will give way to an all-embracing black starry sky. The earth together with the sun and moon will only be the principal bodies of the night sky against the background of a sphere of constellations. Then the constellations will be still more important. The stars will be the sole points of orientation for long-distance spaceflights.

Comet seekers must have a very good knowledge of constellation patterns. When a tiny fuzzy dot of a new comet appears among the multitude of faintly blinking stars, it may easily be confused with distant nebulae that stud the skies in profusion. But if the observer knows where the nebulae are positioned, he will avoid distressing errors.

Time and again, astronomical amateurs, not specialists, have been first to detect the sudden outburst of a new star (nova). One obviously has to know his constellations to be able to pinpoint the "extra" luminary.

This book is aimed not only at the astronomical devotee taking his first steps among the constellations and making his first attempt to learn about the universe on his own. It has in view readers of popular astronomical literature who do not conduct scientific observations of celestial bodies but would like to see the actual objects they have read about. This is to be encouraged, of course, because no drawing or even the best photograph can bring out that feeling of satisfaction which one experiences when contemplating living nature. Such contemplation is always both pleasurable and instructive.

This book is not intended as a dry reference work, nor is it a text for recreative reading. The author had in view a handbook for independent astronomical observations, a thing quite accessible to every single person. The idea—as in the case of every guidebook—is to combine reading of the explanatory material with observations. Only then will the reader obtain something more than ordinary books give: the joy of direct contact with nature, with the infinite scintillating diversified universe.

THE NAMES OF THE CONSTELLATIONS

The novice is always startled by the strange names of the constellations when he begins his study of the night sky. As a rule, even a person with a great deal of imagination is not able to picture what the name of the constellation calls for. For instance The Great Bear (at least the principal portion of it) is more like a dipper, while the randomly scattered groups of faint stars all about it—they go by the names The Giraffe and The Lynx—don't resemble these at all.

No less strange is the variety of names. The night sky accommodates constellations like The Shepherd and The Sextant, The Hydra and The Fly, The Microscope and The Lizard. Quite a chaotic collection, to say the least, but there are reasons.

The starry sky reflects a variety of historical periods and the creative efforts of different peoples. The presently accepted, so-called official, star maps with their 88 constellations have brought to completion the many-centuries' efforts of mankind and have immortalized in the sky objects that do not always deserve it. In the history of the constellations we find much that is arbitrary and often simply absurd. At times we simply cannot find the motives for constructing a given constellation, and to this day there are debatable cases as to what the designations of certain constellations actually signify. Even the final list of 88 constellations is based not so much on logic as a desire to preserve without change the historically established picture of the sky.

We will not attempt to relate the history of the constellations, for this is too broad a topic, but will confine our-

selves to a brief description of the constellations by name; later on we will describe each constellation in detail and speak about the origin of its designation.

Of the 88 modern constellations, many have come down to us from antiquity. They were known for a long time before the Christian era and were mentioned in the Bible, in the works of Homer, Hesiod, Phales, Eudoxus, Hipparchus and other ancient writers. Here are the names of these most ancient constellations: Ursa Major (The Great Bear), Orion (The Hunter), Taurus (The Bull), Canis Major (The Greater Dog), Boötes (The Shepherd), Ursa Minor (The Lesser Bear), Draco (The Dragon), Hercules (Hercules), Aquarius (The Water Bearer), Capricornus (The Sea Goat), Sagittarius (The Archer), Sagitta (The Arrow), Delphinus (The Dolphin), Lepus (The Hare), Eridanus (The Celestial River), Cetus (The Whale), Piscis Australis (The Southern Fish), Corona Australis (The Southern Crown), Ara (The Altar), Centaurus (The Centaur), Lupus (The Wolf), Hydra (The Hydra), Crater (The Bowl), Corvus (The Crow), Libra (The Balance), Coma Berenices (Berenice's Hair), Crux [The (Southern) Cross], Equuleus (The Little Horse), Corona Borealis (The Northern Crown), Ophiuchus (The Snake-Strangler), Scorpio (The Scorpion), Virgo (The Virgin), Gemini (The Twins), Cancer (The Crab), Leo (The Lion), Auriga (The Charioteer), Cepheus (The Sea Monster), Cassiopeia (Cassiopeia), Andromeda (Andromeda), Pegasus (The Winged Horse), Aries (The Ram), Triangulum (The Triangle), Pisces (The Fishes), Perseus (Perseus), Lyra (The Lyre), Cygnus (The Swan), Aquila (The Eagle). Most of these 47 constellations are of mythological origin. They include personages of the ancient Greek myths and legends. A star map with figures representing the constellations is shown in Fig. 1.

Another group of constellations was first mentioned by the astronomer Johann Bayer, who in 1603 published a magnificent atlas of the stellar sky that included the constellations Pavo (The Peacock), Tucana (The Toucan), Grus (The Crane), Phoenix (The Phoenix), (Piscis) Volans (The Flying Fish), Hydrus (The Watersnake), Dorado (The Swordfish), Chamaeleon (The Chameleon), Apus (The Bird of Paradise), Triangulum Australis (The Southern Triangle), Indus (The Indian). The names of these constellations bring back to us the atmosphere of the great geographical

Fig. 1. Figures of the circumpolar constellations in an old star atlas.

discoveries, when Europeans discovered the exotic landscapes of unknown southern lands. There are hardly any mythological names left, only the real characters of the epoch, such as The Indian, The Peacock or The Bird of Paradise.

Gradually, discoveries opened up the entire globe and European scholars began to map the recently discovered southern sky with new constellations. At the same time certain blank spots in the northern heavens were filled up too.

By the end of the seventeenth century, we find new constellations in the list compiled by the famous Danzig astronomer Hevelius: Camelopardus (The Giraffe), Musca (The Fly), Monoceros (The Unicorn), Columba (The Dove), Canes Venatici (The Hunting Dogs), Vulpecula (The Fox), Lacerta (The Lizard), Sextans (The Sextant), Leo Minor (The Lesser Lion), Lynx (The Lynx), Scutum (The Shield).

In 1752, a well-known student of the southern stellar sky, the French astronomer Lacaille, added another 14 constellations: Sculptor (The Sculptor), Fornax (The Furnace), Horologium (The Clock), Reticulum (The Net), Caelum (The Chisel), Pictor (The Painter), Ara (The Altar), Pyxis (The Compass), Antlia [The (Air) Pump], Octans (The Octant), Circinus (The Compasses), Telescopium (The Telescope), Microscopium (The Microscope), Mensa [The Table (Mountain)]. All these constellations lie in the southern hemisphere of the sky. To these we need only add five constellations. In antiquity, three of them—Carina (The Keel), Puppis (The Poop), and Vela (The Sails)—formed the major portion of the constellation of Argo, the mythical ship which according to the ancient Greek legend carried the famed Argonauts to Colchis. The fourth constellation, Serpens (The Serpent), is remarkable in that on star charts it occupies two separate portions of the sky. One might even think that there are two constellations of The Serpent next to each other. Actually, it is one constellation divided by Ophiuchus (The Snake-Strangler). Old star charts depict a man holding a snake. Modern maps have divided this ancient constellation into two: Ophiuchus and Serpens. The last and 88th constellation is Norma (The Square). It is found in the southern sky and has just as arbitrary an origin as The Southern Triangle.

From this brief enumeration of constellations we may conclude that the most ancient got their names from myths; those of the seventeenth and eighteenth centuries have almost nothing to do with classical mythology and their names originated in the fertile imagination of their creators.

So far we have spoken of constellations introduced by Europeans, but this does not at all mean that the peoples of Asia and America did not engage in mapping the night sky. Different peoples saw different things in the stellar patterns of the heavens. For example, in Central Asia,

the Kazakh tribes called the seven-star dipper of The Great Bear "The Tethered Horse". The ancient Egyptians gave it the name "Hippopotamus".

It is interesting to note that in the seventeenth and eighteenth centuries some astronomers of Europe made attempts, for a variety of reasons, to establish new constellations, at times distorting or even eliminating those of the ancients. For instance, the English astronomer Flamsteed in 1725 out of loyal sentiment named the principal star in the constellation Canes Venatici "Cor Caroli" ("Charles' Heart"). This precedent was followed by the English astronomer Hall, who at the end of the eighteenth century placed in the sky "Psalterium Georgii", and the German astronomer Bode, "The Regalia of Friedrich II". Incidentally, in order to clear up a site for "The Regalia" of the Prussian king, Bode "pushed aside" the arm of Andromeda, who had held it extended for three thousand years!

How far things were getting out of hand is shown by the following incident. In 1799 the noted French astronomer Lalande put in the sky a constellation called "Felis" ("The Cats"). The explanation he gave was this: "I like cats, I adore cats. I hope I shall be forgiven if after my sixty years of constant labour I place one of them in the sky."

All these reforming actions of individual astronomers are modest indeed beside the projects for a total "reconstruction" of the constellations proposed by clerical circles in the seventeenth century. One of these projects calls for replacing the "godless pagan" constellations with Christian ones. Here are some instances: Aries was converted into the constellation The Apostle Peter, Pisces, into the constellation The Apostle Matthew, and the like. And that is not all. The sun was to be renamed Jesus Christ, the moon was to become The Virgin Mary. The planets were to reform as well: Venus would have taken the name John the Baptist!

Astronomers, it can well be understood, were firmly against any such reform. The absurdity of the whole thing was evident even to the more advanced thinkers of the church, for if the new designations for celestial bodies were introduced, one would get phrases of a definitely impious slant, such as "Jesus Christ slipped below the horizon" or "Christ was eclipsed by the Virgin Mary"!

Even in the nineteenth century, attempts were made (true, these were the last) to break up the ancient patterns

of the night sky. In 1808 certain sycophantic German scholars proposed changing Orion into the constellation of Napoleon. The amusing thing is that even the French astronomers found this quite out of place.

The International Astronomical Congress of 1922 finally established order in stellar affairs. The Regalia of Friedrich, The Cat of Lalande and 27 other luckless constellations were discarded, and strict boundary lines were set up between the remaining 88 constellations.

Some of the delegates to the Congress proposed abolishing the constellations altogether, substituting in their place quadrangular areas of standard size. The majority however rejected this idea. The Congress retained the ancient and old designations of the constellations. True, the modern investigator of the sky finds hardly any need for them since stellar work is done by means of coordinates. But constellations are useful in gaining an initial and general understanding of the night sky. And what is most important, these are monuments of ancient culture that reflect in a peculiar fashion the various stages in the development of astronomy.

A GENERAL SURVEY OF THE NIGHT SKY

Before taking up our study of the individual constellations and their sights let us examine in brief the principal types of population in the stellar world. This general overview of the picture will relieve us of repetitions when investigating details later on.

What kinds of objects will we encounter in our observations?

Above all, stars. Spectral studies tell us that these celestial bodies are similar in nature to our sun. Stars differ in dimensions, density, colour, and temperature. The chemical composition is roughly the same, although the percentage content of various substances in the different stars varies. The dominant elements are hydrogen and helium, the other chemical elements being much less abundant.

The spectra of stars are extremely multifarious, and the reason is not the different chemical makeup but mainly the very substantial difference in their temperatures.

When observing stars, one notes a variety of colours: some white or blue, others yellowish and even red. These colour differences are associated with temperature differences. The hottest stars are white and blue.* They have surface temperatures ranging from 10,000°C to 30,000°C. ** Then there are exceptional stars with even hotter surfaces, of the order of 100,000°. Yellow stars—our sun is in this category—are cooler with surface temperatures close to 6,000°. And the coolest stars are red, with surface tempera-

* Strictly speaking, there are no blue stars, only bluish-white. The intense blue colour of certain stars is due to the subjective peculiarities of our vision.

** All temperatures are given in Celsius (centigrade).

tures of no more than 2,000°. In the deep interiors of stars the temperature goes up to many millions of degrees.

One of the most important physical characteristics of stars is their *luminosity*. Luminosity is described by a number that indicates the amount of light of a star relative to the sun. For example, if a star has a luminosity of 1,000, this means that it radiates one thousand times more light than the sun. Stellar luminosity depends both on the dimensions of the surface of the star (for equal temperatures, larger stars emit more light), and on its temperature (among stars of the same dimensions those with higher temperatures radiate more intensively). Stellar luminosities are highly diversified. There are stars that emit hundreds of thousands of times more light than the sun. But there are also stars that have luminosities just as many times lower than that of our sun.

Stars with great luminosity are called *giant stars*; if the luminosity is low, they are *dwarfs*.

The luminosity of a star is one of the important characteristics of its dimensions.

Stars have a great variety of dimensions. There are giants with diameters hundreds of times that of the sun, and there are also stars (in the dwarf class) that are about the size of the earth.

It is interesting to note, however, that the masses of all stars are much alike, and rarely do we encounter one that is several tens of times "heavier" or "lighter" than the sun. Which immediately suggests that the mean densities of stars should come in a variety of styles.

Indeed, the substance matter of the giant stars is extremely tenuous, having densities thousands of times less than the density of air at ground level. Now the so-called white dwarfs, which are very hot small stars, have an average density tens of thousands of times that of water.

Astrophysics has explained the causes of this high density of stellar matter. The interiors of white dwarfs have fantastic temperatures and pressures. As a result, the atoms are totally ionized, which means that all electrons have been stripped from their nuclei. The separate escaped electrons together with the bare atomic nuclei now form a superdense mixture of what is known as *degenerate gas*. In a degenerate gas, the atomic nuclei, which contain the

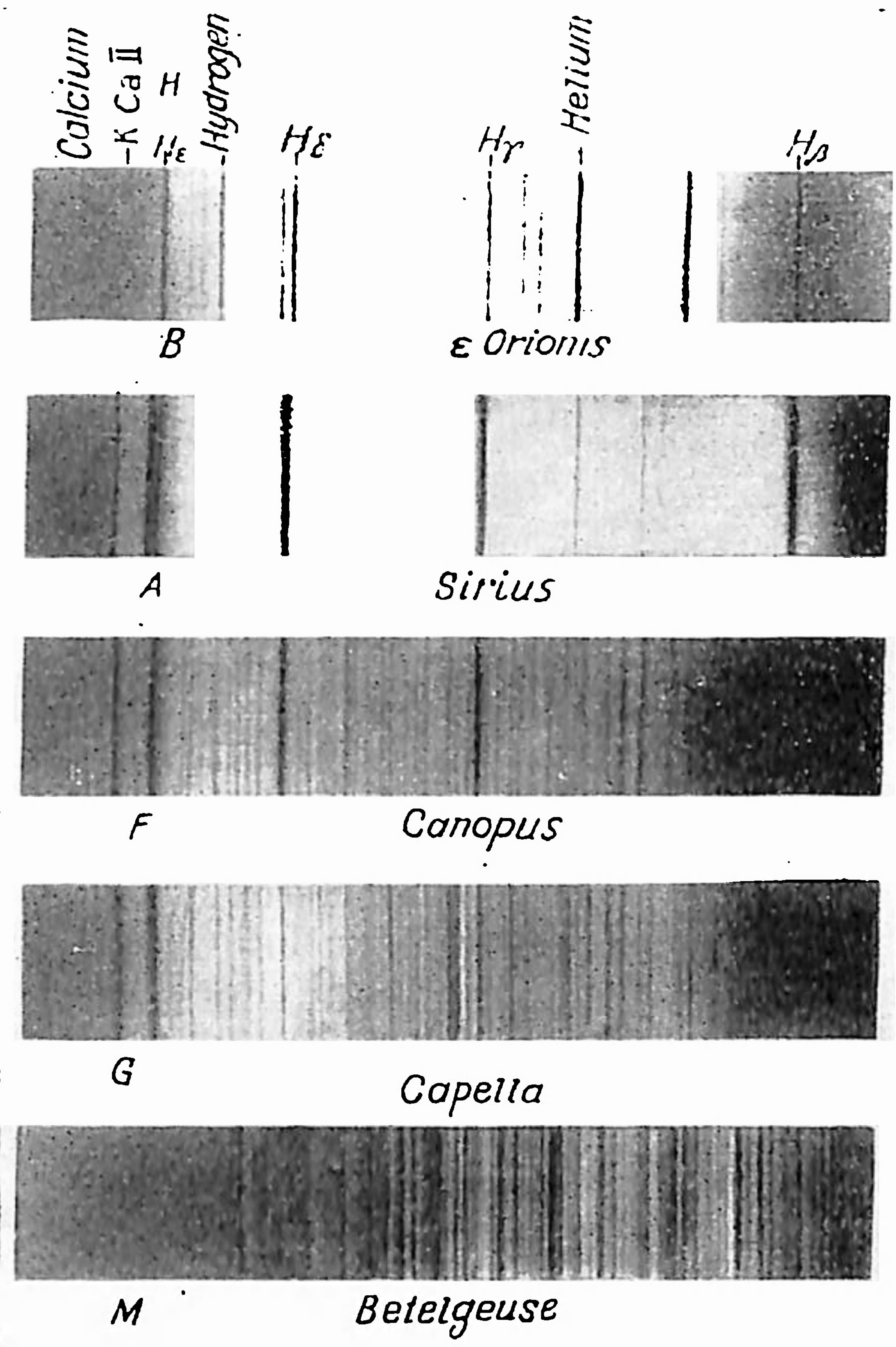


Fig. 2. Classes of stellar spectra.

basic mass of matter, lie much closer together than under ordinary terrestrial conditions.

Studies of the physical nature of stars are of great importance to modern physics. Stars are often justly called "celestial laboratories". By observing them we are able to study matter under states that are frequently far beyond the potentialities of any earth laboratory.

A comparison of the physical nature of the sun and stars shows that the sun is a very ordinary, run-of-the-mill star (as to spectrum, colour, luminosity, dimensions, and so forth).

As we have already pointed out, the differences in stellar spectra are due not to peculiarities of chemical composition but mainly to differences in the temperature of the star's atmosphere. At the present time astrophysics has a unified classification of stellar spectra. They are divided into classes according to type, each class being denoted by a letter. The following are the spectral classes of stars:

$$\begin{tikzcd} & & & & & R \arrow[r, dash] & N \\ O \arrow[r, dash] & B \arrow[r, dash] & A \arrow[r, dash] & F \arrow[r, dash] & G \arrow[r, dash] & K \arrow[u, dash] \arrow[d, dash] \arrow[r, dash] & M \\ & & & & & S & \end{tikzcd}$$

There are two branches off the main group: classes R, N and S. These classes include a relatively small number of cool stars whose spectra exhibit bands of molecules of carbon and cyanogen (classes R and N). The spectra of Class S reveal bands of the oxides of titanium and zirconium. Fig. 2 illustrates the spectra of a number of stars.

The physical characteristics of the basic spectral classes are summarized in the following table.

Intermediate spectral classes such as O5, B7, A2, etc., have been introduced to improve the accuracy in classifying stellar spectra as to intensity of lines and bands of absorption. If the star belongs to the dwarf class, a "d" is prefixed, if to the giant class, a "g", and "s" for supergiant (for example, dM5, gA2, etc.).

The spectra of certain hot stars contain bright emission lines and bands. In this case, the spectral class is designated by an additional "e". When the spectrum of a star is unusual, "p" (for particular) is added (e.g., O5e or F3p). A knowledge of this system of symbolism is absolutely necessary for anyone who wants to make use of tables of the physical characteristics of individual stars.

To describe the *apparent brightness* (*apparent brilliance*) of stars, arbitrary units called *stellar magnitudes* have been introduced.

In antiquity, the brightest stars were called stars of the first magnitude, and the faintest (just barely visible to the unaided eye), stars of the sixth magnitude (we shall designate them thus: Mag. 1, Mag. 2, etc.). Subsequent revisions and extensions of this *scale of star magnitudes* made it imperative to introduce intermediate fractional and

Classification of Stellar Spectra

Class	Characteristic	Temperature	Typical stars
O	Lines of hydrogen, helium, ionized helium, and multiply ionized silicon, carbon, nitrogen, and oxygen. Stars with emission lines in the spectrum are called Wolf-Rayet stars (temperatures reach 100,000°).	25,000°-35,000°	ζ Puppis λ Orionis ξ Persei λ Cephei
B	Lines of helium, hydrogen (are intensified as Class A is approached). Weak H and K lines of ionized calcium.	15,000°-25,000°	ε Orionis α Virginis (Spica) γ Persei γ Orionis
A	Hydrogen lines very intensive, H and K lines of ionized calcium get stronger as Class F is approached; weak metallic lines appear.	11,000°	α Canis Majoris (Sirius) α Lyrae (Vega) γ Geminorum
F	The H and K lines of ionized calcium and metallic lines become stronger as Class G is approached. Hydrogen lines become weaker. A calcium line (λ 4226 Å) appears and grows stronger as Class G is approached. The G band of hydrocarbon appears and becomes stronger.	7,500°	δ Geminorum α Canis Minoris (Procyon) α Persei
G	The H and K lines of calcium are prominent. Line 4226 Å and iron line rather prominent. Many metallic lines. Hydrogen lines become weaker as Class K is approached. G band is prominent.	6,000°	α Aurigae (Capella) the sun
K	Metallic lines, particularly H, K and 4226 Å, are prominent; hydrogen lines hardly perceptible. G band is prominent. From Subclass K5 absorption bands of titanium oxide (TiO) are apparent.	4,500°	α Boötis (Arcturus) β Geminorum (Pollux) α Tauri (Aldebaran)

Continued

Class	Characteristic	Temperature	Typical stars
M	Prominent absorption bands of titanium oxide and other molecular compounds. Metallic lines are noticeable, particularly H, K and 4226 Å; G band becomes weaker. The spectra of long-period variables (of the *o* Ceti type) have emission lines of hydrogen (designation: Me).	2,000°-3,500°	α Orionis (Betelgeuse) α Scorpii (Antares) *o* Ceti

(for very bright objects) zero and negative magnitudes (Mag. 0, Mag. —1, and so on).

Let I_1 and I_2 be the brightnesses of two stars, that is, the *illumination* produced by these stars on a receiver of energy (the human eye, a photographic plate, and the like), and m_1 and m_2 the respective star magnitudes. Thorough investigations have shown that these quantities are connected by a simple relation, called Pogson's formula:

$$\frac{I_1}{I_2} = 2.512^{m_2 - m_1}$$

Taking the logarithms of both sides of this equation, we have

$$\log \frac{I_1}{I_2} = 0.4\ (m_2 - m_1)$$

Thus, stars that differ in apparent brightness by one magnitude create on the earth a difference of illumination of about 2.5 times.

To describe the luminosity of stars, astronomers have introduced the concept of *absolute stellar magnitude* (denoted by M). This term is to be understood as the apparent brightness of a given star at a distance of 10 parsecs (one parsec is equal to 3.26 light years). To illustrate, the sun has M=Mag. 4.7. This means that from a distance of 10 parsecs the sun would appear to be a star of about the fifth magnitude. Rigel (the brightest star in the constellation Orion) has M=Mag. —6.2. Using Pogson's formula we can calculate that Rigel emits roughly 23,000 times as much light as our sun.

A particularly vivid picture of the physical peculiarities of stars can be obtained if we take advantage of the

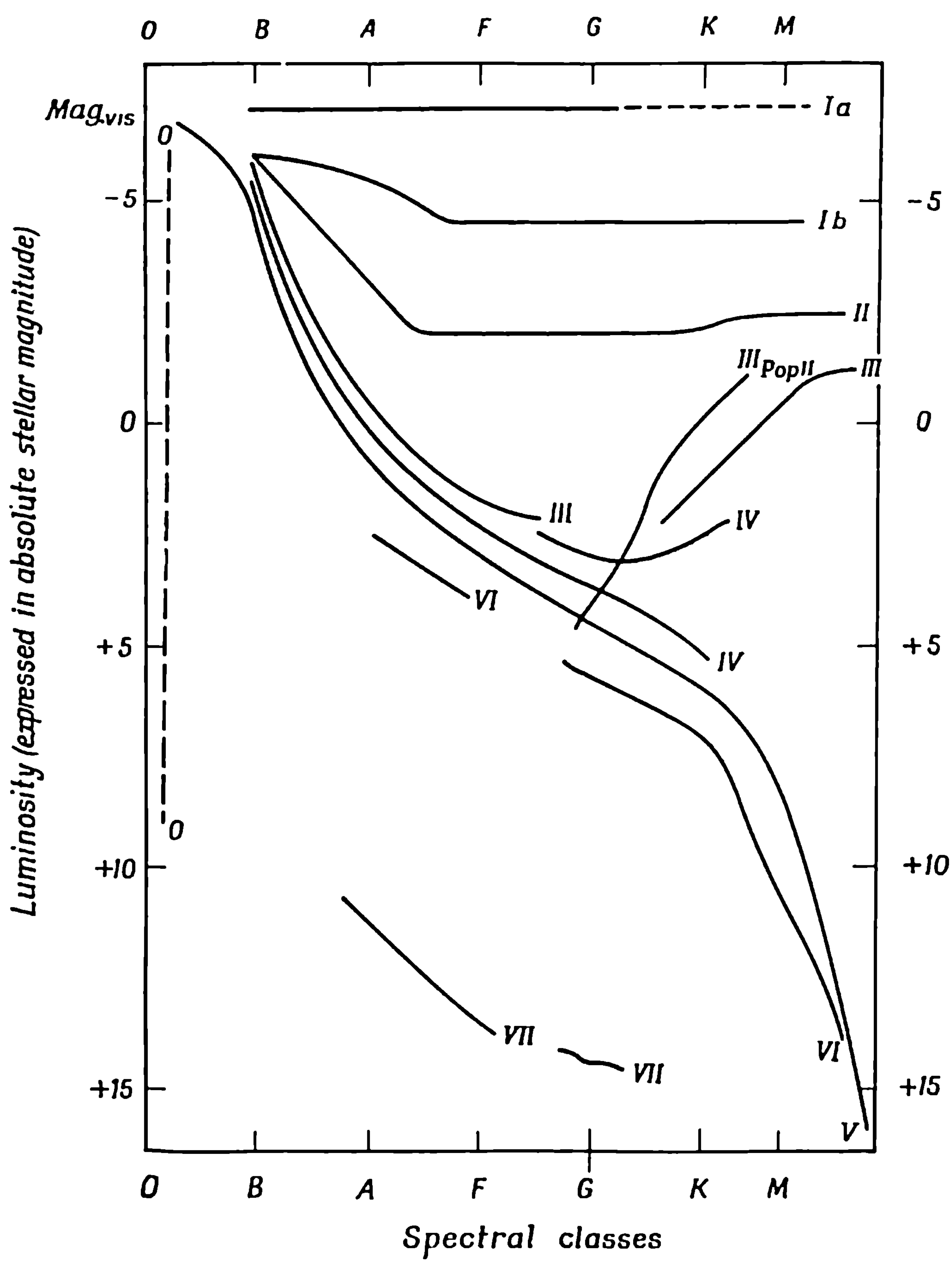


Fig. 3. Star sequences on the Spectrum-Luminosity Diagram:
Ia—sequence of bright supergiants; *Ib*—weak supergiants; *II*—bright giants; *III*—weak giants; $III_{p_{II}}$—Population II stars of the Galaxy; *IV*—subgiants; *V*—main sequence; *VI*—sequence of bright subdwarfs; *VII*—subdwarfs (white dwarfs); *O-O*—white-blue sequence. The diagram represents data on 4536 stars down to the sixth magnitude.

spectrum-luminosity diagram. Referring to Figs. 3 and 4, we have the spectral classes laid off on the horizontal axis, and the absolute stellar magnitudes which characterize luminosity on the vertical axis. Each star, and the sun as well, has only one distinct position on this diagram. Studies of several thousand stars have demonstrated that the spectrum-luminosity diagram exhibits stars in the form

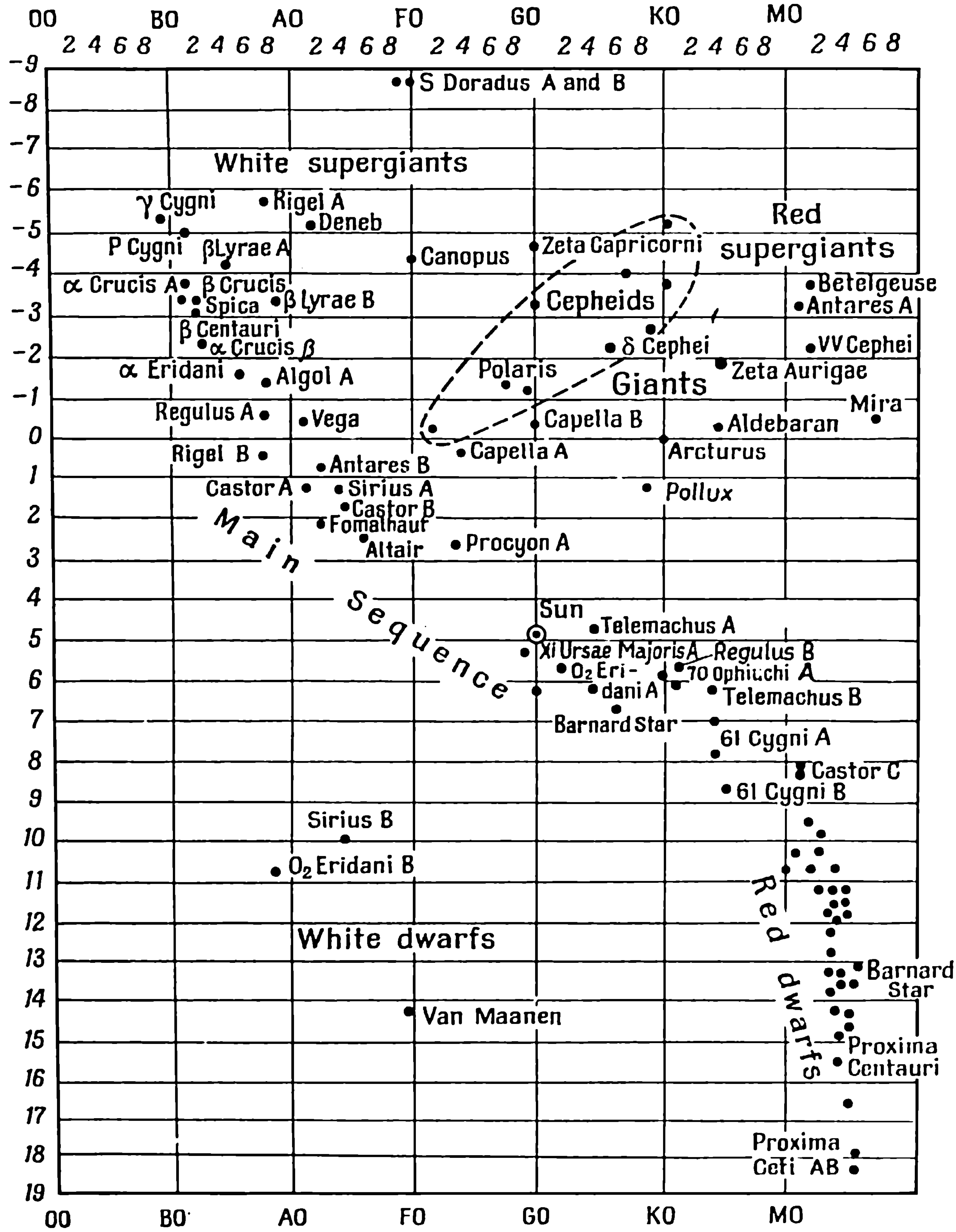


Fig. 4. The positions of some stars on the Spectrum-Luminosity Diagram.

of chains, or groups, or (as they are termed) sequences. Each sequence is appropriately designated in the caption to the diagram. To take an instance, the sun lies on the main sequence (*V*), while the horizontal straight line in the upper part of the diagram (in the region of high luminosities) depicts the branch of supergiants (*Ia*). The identification of a star in a given sequence, together with its luminosity and spectrum, gives a full description of the physical properties of the star.

In antiquity the stars were believed to be fixed and the constellation patterns unchanged. However, at the beginning of the eighteenth century it was found that some stars have definitely moved relative to others since the days of Hipparchus (first century B.C.).

At the present time, it has been rigorously proved that the stars are in motion in space. This motion can be detected in two ways: by the apparent shifting positions of certain stars and by the stellar spectrum.

Since stars are extremely far away from the earth, the apparent displacements on the celestial sphere are negligibly small and, at best, are measured in seconds of arc per year. For this reason, although the relative positions of the stars in the sky are gradually undergoing change, any distortions in the familiar patterns of the constellations will become noticeable only tens of thousands of years hence. We can notice a shift in the stellar positions on the celestial sphere by comparing photographs of the sky made at intervals of several years. Measurements of these photographs may be used to compute the *tangential* velocity of a star (if we know its distance from us), that is, the velocity perpendicular to the line of sight.

A spectral analysis permits finding the velocity of a star along the line of sight. According to the Doppler-Fizeau principle, the spectral lines of an approaching star are shifted towards the violet end of the spectrum; for a receding star the shift is towards the red end. The magnitude of this shift readily gives us the *radial* velocity of the star (that is, its velocity along the line of sight).

Knowing the tangential velocity V_t and the radial velocity V_r of a star, we can compute the total velocity of motion in space. Obviously,

$$V = \sqrt{(V_t)^2 + (V_r)^2}$$

As a rule, total stellar velocities come out to tens of kilometres a second. In this respect, our sun is no exception. Together with its family of planets, the sun is moving relative to the nearest stars with a velocity of 20 km/s, thus covering over a million kilometres every day. The path of the earth in interstellar space thus comes out in the form of a complicated helicoidal curve.

In the direction that our solar system is moving, the stars appear to be slowly moving outwards. This is the impression one gets when approaching a wood, the trees of which appear as a solid wall from a considerable distance.

Although stellar velocities are great, there can be hardly any chance of a collision of stars due to the enormous distances between them as compared with their diameters. These distances are so great that the kilometre is no longer a convenient unit. In stellar astronomy we use the *light year*, which is the distance that light travels in one year ($9.46 \times \times 10^{12}$ km), the *parsec* (which is 3.26 light years) and the *kiloparsec*, or a thousand parsecs. If we reduced the stars to the size of pinheads, then one star would be tens of kilometres from the others. Using the same scale, we would get displacements of stars in one year of only tens of centimetres.

Astronomers have established that in addition to translational motion, stars have rotational motions about their axes as well.

Some stars, which to the unaided eye appear as a single object, break up into two components when viewed in a telescope. These are called *double* stars. Some of them are seen from the earth in just about the same direction, but are great distances apart and are not physically connected in any way. These are known as *optical doubles*.

However, many of the double stars are actually close together in space, are mutually attracted via gravitational forces and revolve about their common centre of gravity (or, more precisely, their centre of mass). These physically connected stellar pairs are called *binary* stars.

Telescopic observations sometimes show different-coloured double stars of extraordinary beauty. It must, however, be kept in mind that the bright colours of double stars are caused mainly not by the actual difference in the colours they emit but by complicated subjective errors associated with the physiological peculiarities of vision of the observ-

er. (Appendix IV contains a list of variously coloured double stars.)

The closer the stars are to one another for the same masses, the shorter their periods of revolution about the common centre of gravity. In some cases, these periods are measured in hours, in others, in centuries.

If a binary star has a planetary system, one would be able to see two suns at once! But do such star systems have planets?

Today science gives an affirmative answer. Certain stars move along intricate wave-like curves. These stars attract their invisible companions, thus compelling the star to revolve about the common centre of gravity. Among the invisible satellites of certain stars we have found bodies with masses comparable to the masses of the giant planets of our solar system. This suggests that such stars have planetary systems.

Some binary stars consist of component stars so close together as to be unresolvable even in a telescope. Then spectral analysis comes to our aid.

If we have a binary star, the components revolve about a common centre of gravity, approaching us (in the line of sight) and then receding. By the Doppler-Fizeau principle, their spectra overlap yielding a periodical doubling of the spectral lines, because as one star approaches us, the other is receding from us. A single star does not produce any such phenomenon. Star systems thus detected spectroscopically are termed *spectroscopic binaries.*

In addition to double stars we also encounter triple and even *multiple* stars. In such systems, too, the stellar motion is about the common centre of gravity.

If in a binary star system, the planes of the orbits are close to the line of sight and the stars have different luminosities, there may be times when one of the components will eclipse its companion. For the terrestrial observer, this "stellar eclipse" will amount to a reduction in the brightness of the binary star. Obviously, such variations of brightness will be periodical and may be expressed in the form of a curve (see Fig. 32). These stars are called *eclipsing binaries* or *eclipsing variables.*

There are other kinds of variable stars as well.

In eclipsing variable stars, the variation of brightness is due to optical factors (eclipses). In other variables,

the luminosity, and hence the brightness, changes due to physical factors. Do not confuse variation of brightness with the twinkling of a star, which is brought about by purely terrestrial causes (movements of air masses).

First of all, physical variables include such stars as the so-called Cepheid variables. Stars of this class periodically expand (their temperature then drops) and contract (a heating-up process sets in). This gives rise to variations in their apparent brightness.

The periods of variation of brightness of Cepheid variables are closely associated with their luminosity. If we find the luminosity of a Cepheid from the period and if we know its apparent brightness, it is easy to compute the distance to this variable star and, what is most important, to the object in which the Cepheid is located. This is a commonly used method for determining the distances to stars. The Cepheids are sometimes called "beacons of the universe" because they give a clue to the distribution of stars in space.

There are some stars with periodically varying brightness (like the Cepheids) but with much longer periods. They go by the name *long-period variables* because their periods of variation of brightness are often measured in hundreds of days.

In some variable stars the pulsations are rather chaotic without any signs of periodicity. They are called *irregular* or *semiregular variables.*

Over 15,000 variable stars are presently on record. Their study opens up many aspects of the physical nature of stars.

Another class of stars includes those which increase their brightness to tens and hundreds of thousands of times very rapidly, in a day or two. Then such a star begins to lose brightness, first rapidly and then more slowly. In a few years it returns to the same status it had before the outburst or becomes even fainter. These are called *novae*. At one time they were thought to be totally new stars. Actually, such stars exist before their outburst. What is more, in some cases, apparently, there are several outbursts in the course of the star's lifetime. When a nova explodes, the outer layers of gas of the star race out at velocities of thousands of kilometres per second and gradually disperse into interstellar space.

Our sun belongs to the class of stable stars that are not subject to outbursts characteristic of the new stars.

The outbursts of particularly bright novae (called *supernovae*) produce enormous rarefied gas clouds (nebulae) with intensive emission of radio waves.

On dark winter nights, in the constellation Taurus, one can see a tiny close-knit group of six faint twinkling stars. This is the Pleiades *star cluster*. A telescope reveals many more stars, over a hundred. They are all close together, and not only in the sky but in actual space and are linked together by gravitational forces.

Thus, unlike constellations, which are only apparent patterns of stars in the sky, the individual members of which are actually far away from each other, *star clusters are physically related by mutual gravitational forces and form groups.*

Star clusters with irregular outlines are called *galactic*, or *open*, *star clusters*. The tens or hundreds of component stars are haphazardly scattered over a small area of the sky. The Pleiades typify such a cluster.

Globular star clusters are different in shape. They contain hundreds of thousands of stars. There are so many stars in the central region of a globular cluster that they merge into a solid radiance.

Globular clusters are many times larger than galactic clusters. Some globular clusters are two and three hundred light years in diameter, whereas on the average galactic clusters are only about 10 to 20 light years across.

At the present time, about five hundred galactic clusters and a hundred globular clusters have been recorded and studied. Both types of clusters move in space as one whole.

The space between stars is not absolutely empty. It is filled with extremely tenuous clouds of dust and gas, which astronomers call *diffuse interstellar matter*.

These enormous interstellar clouds of luminous rarefied gases and dust have become known as light diffuse nebulae. A typical representative is the bright nebula in the constellation Orion, which is clearly visible in field-glasses. The component gases shine with a cold light, reflecting the light of neighbouring hot stars. Thus, the glow of gaseous nebulae is a luminosity like that we also see in comets.

The components of light diffuse gaseous nebulae are mainly hydrogen, oxygen, helium and nitrogen. Nebulae are tens and occasionally hundreds of light years in diameter. Like comets (and with even more justification), inter-

stellar gaseous nebulae may be called "visible nothings" since the density of the matter is thousands of millions of times less than that of air at sea level. This is a degree of rarefaction that terrestrial technology has not yet been able to achieve.

Interstellar space also has what is called diffuse dust nebulae. These are clouds of minute solid dust particles with mean diameters of the order of a tenth of a micrometre. If there is a bright star nearby, its light scattered by the dust nebula makes the latter visible. In many cases dust nebulae belong to the class of dark nebulae. In which case they are seen as gaping voids against the background of the Milky Way.

There is no unsurmountable barrier between gaseous and dust nebulae, whether light or dark. They are frequently seen together as gas-and-dust nebulae. It may be that in certain cases the glow of some nebulae is due to the interpenetration (collision) of two or more clouds.

Nebulae are apparently only slight condensations in the otherwise extremely tenuous diffuse interstellar matter that we know as *interstellar gas*. This medium reveals itself only in spectroscopic observations of distant stars causing extra absorption lines. The delicate interstellar gaseous veil is hundreds of times more tenuous than the most rarefied of the gaseous nebulae. It consists of atoms of hydrogen, calcium and certain other elements.

Despite its tenuity, the diffuse interstellar matter (gases and dust) produces a measurable absorption of stellar light. This was suspected as early as 1847 by the founder of the Pulkovo Observatory, V. Struve, but it was not until the twentieth century that absorption of light in interstellar space was actually proved.

Interstellar gases and dust distort the light of distant stars in two ways. They weaken the overall brilliance or brightness (general absorption) and make the light of the star redder (selective absorption). Both these effects must be taken into account when computing stellar distances, otherwise gross errors are possible.

A particular place is occupied by the so-called planetary nebulae. Many of them outwardly resemble the smoke rings that skilled smokers make. In a telescope, some of the planetary nebulae resemble the greenish discs of distant planets, like Uranus and Neptune. Whence the term.

Planetary nebulae are not large in size, rarely exceeding 2 or 3 light years. In the centre, there is always a very hot central star, the light of which is re-emitted by the nebula. Therefore, as to type of emission, planetary nebulae belong in the class of light diffuse gaseous nebulae. However, they have their peculiarities. Planetary nebulae are expanding in all directions from the central star, which might have formed the nebula.

Besides gas and dust, interstellar space is filled with fast moving electrons and the nuclei of a variety of elements. These make up the so-called cosmic radiation (cosmic rays). There are also streams of minute packets of light called photons, or the light emission of stars.

On dark autumn nights, one can see a faintly shining whitish band of irregular outline stretching across the sky from horizon to horizon. This is the *Milky Way*. This band stretches round the whole sky, going below the horizon, spreading in and out and varying in brightness.

In a telescope, the Milky Way breaks up into a multitude of faint stars, which to the unaided eye appear as a continuous stretch of radiance.

The Milky Way forms the principal portion of stars that make up our Galaxy, which is an enormous stellar system including our sun as just another ordinary star.

If examined from the side, our Galaxy would appear flat like a lens. In the centre is a dense globular-like cluster of massive stars forming the nucleus of the Galaxy. Unfortunately, observations from the earth do not reveal this because it is hidden from the terrestrial viewer by thick clouds of dark cosmic dust. However, though the dust blocks visible light, it lets through invisible infrared rays that may be received by a special instrument (called an image converter tube). In this way astronomers study (true, with great difficulty) the nucleus of our stellar system.

As has already been mentioned, our Galaxy is made up of about 150,000 million stars, which include all those we see in the sky and the whole Milky Way. The solar system is located near the equatorial plane of the Galaxy, about half way between the centre and the outer boundary. More precisely, our sun is about 23,500 light years from the centre of the Galaxy, which is close to 85,000 light years in diameter. It should be noted that the boundary lines of the Galaxy are not clear-cut and gradually fade out.

It will be readily realized that the Milky Way, as it is seen in the sky, is due to our position within the Galaxy. Observations from the earth show most of the stars in the direction of the equatorial plane of the Galaxy, the smallest numbers being in directions perpendicular to it. For this reason, among other things, the galactic nucleus lies inside the Milky Way in the sky, and in the absence of cosmic dust would be seen in the constellation of Sagittarius.

The Galaxy contains single stars, double stars, variables, and also star clusters and nebulae. It has been found that the diffuse interstellar matter is concentrated in a relatively thin layer in the equatorial plane of our stellar system. Globular clusters are encountered at a wide range of distances from this plane.

Structurally, the Galaxy is extremely complicated. Regarded from above, it would look like an enormous spiral with arms coming out of the nucleus. The Galaxy has been found to consist of a number of interpenetrating subsystems of homogeneous objects (stars, star clusters, nebulae). Some of these subsystems (for example, the subsystem of globular star clusters) embrace our Galaxy on all sides in the form of a gigantic globular swarm. Other subsystems, such as that of planetary nebulae or white dwarfs, are "flattened" to the equatorial plane of the Galaxy. In other words, it is only the framework (or bulk) of stars of the Galaxy that forms the flattened stellar spiral.

All the stars of our Galaxy are in revolution about the centre, having different orbital periods that increase with distance from the centre. It has been calculated that the sun together with its planets makes a complete circuit about the galactic nucleus approximately once every 200 million years, moving with an orbital velocity close to 250 km/s. The solar system is also in motion relative to its neighbouring stars. This motion, which we have already mentioned, is now directed towards the constellations Lyra and Hercules.

The sun and other stars of the Galaxy perform very complicated motions.

A keen-sighted person looking in the direction of the constellation Andromeda will see a tiny oval-shaped faintly luminous spot. A small telescope reveals something like an ordinary light gaseous nebula. Actually, this spot,

Fig. 5. The M51 galaxy in Canes Venatici.

called the Andromeda Nebula, is quite different from a gaseous nebula.

Powerful modern telescopes are able to resolve a gigantic stellar system, in no way inferior to our Galaxy. It is only due to its great distance (light rays from it take nearly 1,700,000 years to reach the earth) that the nebula in Andromeda appears as a faint patch of luminosity. Actually, in diameter it is greater than the Galaxy and is composed of many tens of thousands of millions of stars, star clusters and nebulae.

The Andromeda Nebula faces us edge-on, but still we can easily recognize its spiral structure, the same as that of our own Galaxy. The Andromeda Nebula is a neighbour-

ing galaxy, one of the many millions now accessible to observation. Some are seen flat-on; others, edge-on, clearly exhibit a dark band of dust matter.

Fig. 5 is a picture of two galaxies: an enormous spiral galaxy and a "blob" below it. They are connected by an arm of the main galaxy. Very many galaxies are of this connected type. Galaxies come in a great variety of shapes and do not always resemble spirals. A large number of galaxies are in a state of complex interaction and sometimes interpenetration.

The dimensions of large galaxies are comparable with those of our stellar system, and the distances between them are roughly ten times their diameters. The Andromeda Nebula and many other galaxies rotate on their axes, or, to put it more precisely, the component stars revolve about the nuclei of the galaxies.

Intergalactic space is not empty, it is filled with an extremely tenuous medium called the intergalactic plasma. The most distant of the observable galaxies are several thousand millions of light years away. That is the radius of the presently known universe.

Galaxies are not evenly distributed in space and we sometimes encounter whole clusters of them. Certain facts suggest that all the presently observable galaxies are elements of a grandiose material system called the Metagalaxy. Here, the individual galaxies play the role of stars and are in revolution about some kind of extremely distant centre.

Due to the fact that the dimensions of the Metagalaxy are far beyond the presently observable portion of the universe, available information is extremely meagre. Detailed studies of this entity are a thing of the future.

As man pushes deeper and deeper into the universe telescopically, he encounters new worlds and fresh material systems in states of continual motion and change.

The entire experience and historical practice of mankind (the history of astronomy for one thing) serve as a vivid confirmation of the teachings of dialectical materialism concerning the infinitude of the universe both in time and in space.

Such is the general picture of the stellar world which we are now about to investigate in more detail.

HOW TO STUDY THE CONSTELLATIONS

We shall study the constellations in three ways: visually (naked-eye) and with binoculars and telescope. For our purpose that will be quite sufficient, although astronomers investigate the stellar world with a wide range of modern tools of research. As a rule, they prefer the eye to other more objective receptors of radiation, photographic plates, say. A diversified range of photoelectric devices are also in use in which light rays are caused to produce electric current. Our knowledge of the stellar world has been expanded greatly by the techniques of radio astronomy. Radio telescopes—quite beyond the means of the amateur—have penetrated to distances that are beyond the range of ordinary optical telescopes.

We have mentioned the latest methods of studying the universe in order to stress again the restricted nature of our facilities and our problems. But even with these limited opportunities, studies of the constellations will be useful to all who have an interest in the science of the stars.

Our observations will only be *visual*, the human eye being the final receptor of the emissions of the heavenly bodies. It is natural therefore to begin a discussion of the merits and shortcomings of this marvellous organ of cognition that nature has endowed us with.

Fig. 6 is a schematic diagram of the human eye. The outermost layer is the cartilaginoid *sclera*, with its forward part called the *cornea*. The cornea is transparent, convex and has a spherical-like surface. The inner layer of the eye, containing a ramified network of blood vessels, is called the *choroid*. In different people the forward part of the choroid is coloured differently. It goes by the name *iris*. The

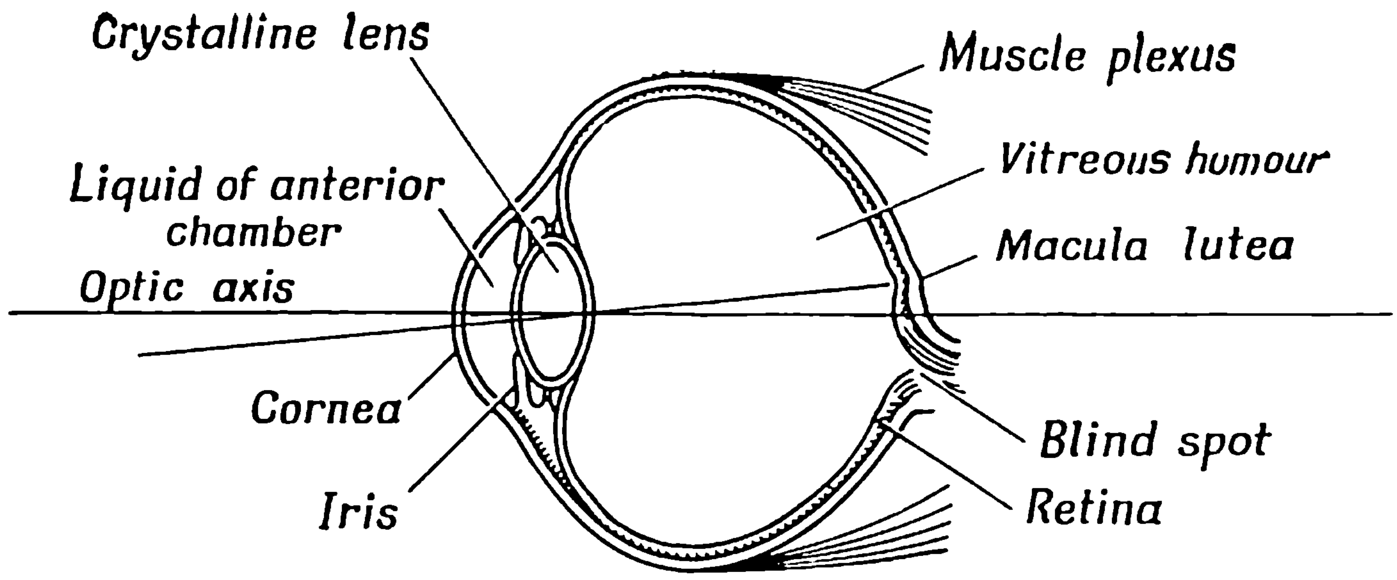


Fig. 6. The structure of the eye.

space between the cornea and the iris is filled with a transparent organic substance.

Take a mirror and examine your eye structure. In the centre of the coloured circle (the iris) is a large dark aperture called the *pupil*. Its role in the eye is that of a diaphragm. When the radiation entering the eye is very great, special muscles diminish the diameter of the pupil; when it is dark, the pupil dilates.

Normally in full daylight the diameter of the pupil is around 5 mm. In night observations it increases to 7-8 mm.

The pupil is a special kind of entry to the inner portions of the eye. In direct contact with it is a remarkable element of the eye: the *crystalline lens*. Nature created this natural biconvex lens perfectly clear and with an added property that no man-made lens possesses. Its shape can change and hence also its focal length. The muscles that operate the crystalline lens are able to contract and expand so that the *retina*, which makes up the inner surface of the eye, always produces clear-cut, focussed images. This property of the human eye that enables us to get sharp pictures of the world is termed *accommodation*.

Between the lens and the retina lies a *vitreous body*, a jelly-like mass which is so transparent that light rays passing through the lens reach the retina without practically any attenuation. An image of the object under observation is built up on the retina like on a screen. Now, how is this image converted into perception?

The retina has a fine-grained reticular structure, in which the optic nerve which enters an opening, called the *blind spot*, spreads out in a network. This part of the eye is abso-

lutely insensitive to light, but the remaining part of the retina is covered over with light-sensitive nerve cells of two kinds: *cones* and *rods*.

Outwardly, the cones and rods only faintly resemble what their names suggest.

The rods are more sensitive to light than are the cones. But the cones enable us to distinguish the colouration of objects. Without them, the world would appear black-and-white. It is a curious thing to note that the eyes of nocturnal animals contain only rods, making all objects colourless. Incidentally, human beings see the world almost exclusively with rods in twilight, when the feeble illumination has hardly any effect on the low-sensitive cones. The daylight spectrum of colours fades considerably and at night "all cats are gray".

The light-sensitive cells of the retina are not located uniformly. Cones are dominant in the middle portion near the pupil, rods are more concentrated around the fringes. This accounts for the so-called effect of averted vision, which frequently has to be used when observing stars. When you want to get a better view of a faint star, do not look directly at it, but somewhat obliquely. Then the image of the star is obtained on that part of the retina which is plentifully supplied with rods and we get a better view.

The human eye is an extraordinarily sensitive receptor of radiation. According to the investigations of Academician S. I. Vavilov, it is even capable of distinguishing the quantum nature of light,* which is quite beyond the capabilities of our best optical devices today. At the same time the eye has serious defects. We shall examine only those that affect the observation of stars.

Bright stars always appear radiant. Turn your head to the left or right and the rays will turn too. It is obvious that these stellar rays are illusory, that is, generated by some optical effect due to the scattering of light in the crystalline lens and the vitreous body. To a large extent it is caused by the irregular boundaries of the pupil.

The sensitivity of the human eye to rays of different wavelength differs. The eye is not at all sensitive to the bulk of electromagnetic waves (radio waves, infrared and ultraviolet rays, etc.). We only see those rays whose wave-

* See Vavilov's book "The Eye and the Sun".

lengths lie within 400 to 760 millimicrons (millimicrometres). The eye is most sensitive to dark green rays of wavelength 555 millimicrometres. We are speaking of a normal human eye. Deviations from this standard may be quite appreciable, even up to complete colour blindness.

When observing stars, one must have in view the peculiar properties of the human eye that are called the Purkinje effect and the Galliso effect. They consist in the fact that when comparing two identically bright stars, a red one will appear brighter than a blue one, and when comparing two equally faint stars, the opposite effect occurs.

Generally speaking, visual observations of star colour are always encumbered by subjective errors. This is particularly evident in the observation of double stars (we shall discuss this a bit later).

If one leaves a brightly lit room and goes out into the night to look at the heavens, he will first see only the brightest stars. The eye has to get used to the dark, only then will it acquire the proper sensitivity. This property is called *adaptation*.

It has been told that the famous Italian investigator of Mars, Schiaparelli, took off a whole hour sitting in a completely dark room with open eyes in order to get ready for observations. Only after such total adaptation did he apply his eye to the eyepiece of the telescope. The result was that Schiaparelli saw more than other astronomers, who were said to be "blind" compared with the "eagle's eye" of the Italian.

When observing faint objects of the night sky (particularly nebulae), take advantage of eye adaptation, like Schiaparelli, and let your eyes get used to the dark. Only then will your observations be fully successful.

Assuming that we have trained our vision in this manner, how many stars will be visible to the unaided human eye?

Calculations of this kind have been carried out and it has been found that on the darkest night the normal human eye is capable of distinguishing about 6,000 stars. The different brightnesses of the stars are obvious from the very first glimpse of the night sky.

As a rule, the naked eye cannot see stars fainter than the sixth magnitude. However, very sharp-sighted people under extremely favourable seeing conditions claim to see much fainter stars. For example, at the Lick Observatory

in the United States at mountain altitude, stars of magnitude 8.5 have been observed on very dark and clear nights. At times like those, tens of thousands of stars would come within the range of an observer.

The potentialities of the human eye are limited not only in perceiving the radiation of faint celestial objects, but also in the ability to resolve two close-lying stars in the sky.

Take the letter "O". You see it at an angle close to 30 minutes of arc. Incidentally, that is roughly the angle at which we see the moon and sun from the earth. But they look much larger, you will say. Yes, here we have to do with one of many optical illusions.

If the viewing angle is so small that light rays from two edges of the object enter one and the same cone or rod, the object is perceived as a point without further detail. Knowing that the diameter of the rods and cones is close to 0.004 mm, and the focal length of the lens is about 23 mm, we can calculate that the *limiting viewing angle* at which the eye can resolve the shape of an object and hence separate two stars is close to one minute of arc. That is the angle at which we would see a dot on this page at a distance of three and a half metres.

Quite naturally, this is an average magnitude for the normal eye. There are of course deviations in both directions. But even the keenest eye sees no more than points when observing the stars, for their actual diameters are seen from the earth at angles much less than one minute of arc.

The role of optical facilities used by astronomers in studying the universe consists essentially in improving our vision and in overcoming the shortcomings of the human eye.

Binoculars and telescopes are superior to the eye primarily in two ways: they collect more light and make possible observations of celestial bodies at much greater viewing angles.

Best suited for constellation studies are *prism* binoculars. The optical qualities of the ordinary opera glasses are very much inferior, thus greatly limiting their astronomical use.

Fig. 7 shows a prism binocular in cross section. A ray of light passing through the objective encounters two total reflection prisms. Their purpose is twofold: firstly, they re-

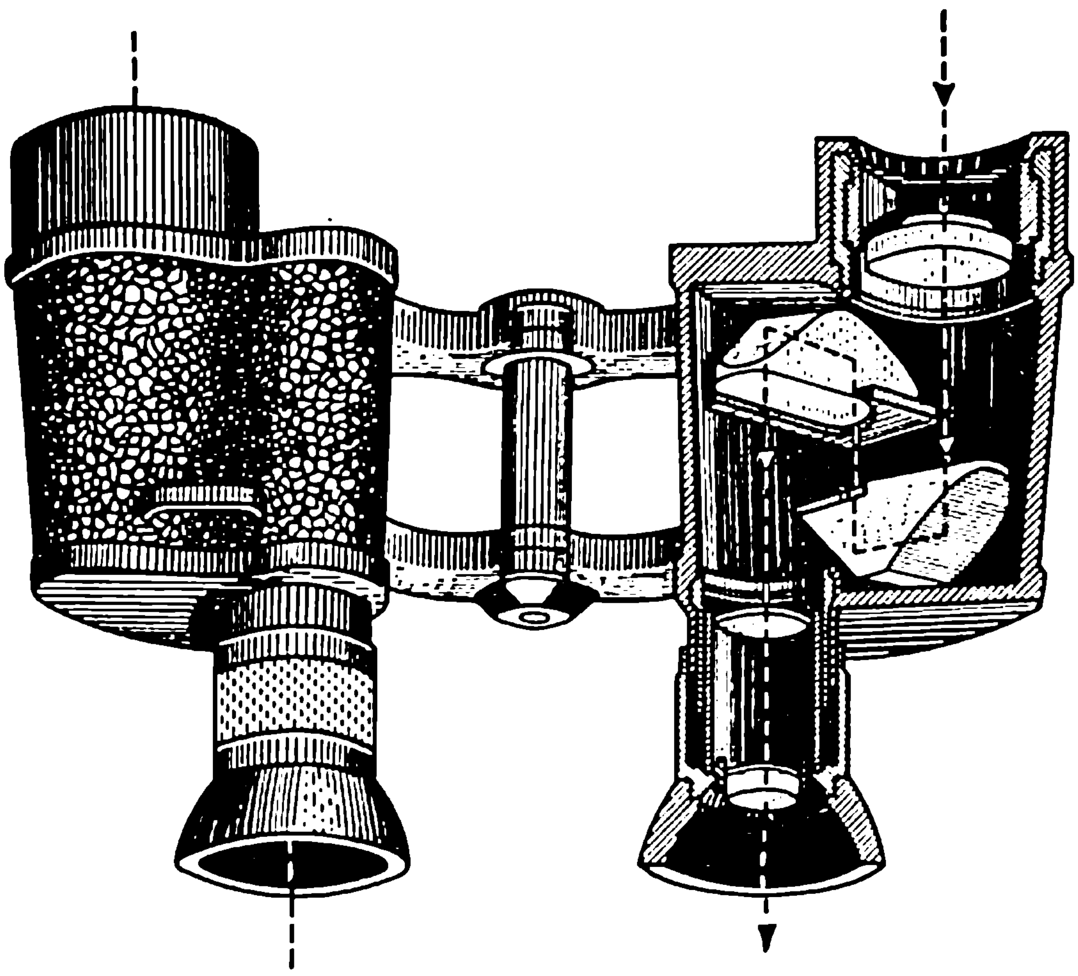


Fig. 7. A prism binocular.

duce the size of the binocular, secondly, they are needed to obtain an erect (uninverted) image of the object. This is not essential for astronomical purposes, but for terrestrial observations it is and has to be taken into consideration.

The image of an object obtained in the objective is examined in the eyepiece, which is actually a magnifying optical system operating like a strong magnifying glass. The eyepieces of a binocular are connected with the body by a screw adjustment system that enables one to focus the image. Focussing is further simplified by a scale on the eyepiece tubes: one needs only remember a given division for the binoculars to be properly focussed.

In prism binoculars the two tubes are connected by an axial piece, rotation about which changes the distances between the eyepieces. Before beginning observations, set the binocular so that the distance between the optical axes of its eyepieces is equal to the distance between the eyes of the viewer.

We will not go into details of design and will note only those qualities that are essential in astronomical observations.

Soviet optical works produce a variety of prism binoculars. The most common is the six-power binocular with 30-mm-diameter objective lens. This binocular has a theo-

retical light-grasp (light-gathering capability) 36 times that of the human eye. Under good atmospheric conditions on a dark night it is possible to see stars down to magnitude 10.5. What this means is that about half a million stars will be visible!

Binoculars also increase the resolving power of the human eye. A six-power instrument is capable of resolving stars that are separated in the sky by no less than 7.5 seconds of arc. True, this is the limit. Practically speaking, the resolving power of optical instruments also depends on the atmospheric conditions, the difference in brightness of close-lying stars, and on other factors, all of which bring the resolving power of the instrument down below its theoretical level.

The field of view in a binocular or telescope has the shape of a circle. The angular diameter of this circle in different instruments varies, and in the same instrument depends on the power used: the higher the magnification, the smaller the field of view.

In Soviet six-power prism binoculars, the field of view has a diameter of 8.5 degrees, which is 17 times that of the apparent angular diameters of the moon or sun.

We also have eight-power prism binoculars with 30-mm objective diameter and, very rarely, ten-power binoculars with a 50-mm objective. The latter instrument is excellent for night-sky observations.

Results are bad if one holds the binocular in his hand during astronomical observations. The hand tires quickly and begins to shake, making the star images jump about. To avoid this, it is best to make a stand of some kind, for example like in Fig. 8. Without a support or stand, astronomical observations with binoculars are almost useless.

Though binoculars have definite advantages over the unaided eye, the chief instrument for studying the constellations is the *telescope*. In recent years, Soviet optical works have put out a large number of excellent instruments that fully satisfy the needs of the astronomy fan. If a factory-made instrument is not available, the devoted star-lover with a little application can make a sufficiently good reflector telescope himself.

The most elementary of the so-called school-type telescopes is a 60-mm-objective refractor equipped with two eyepieces (32-power and 64-power) and has an altazimuth

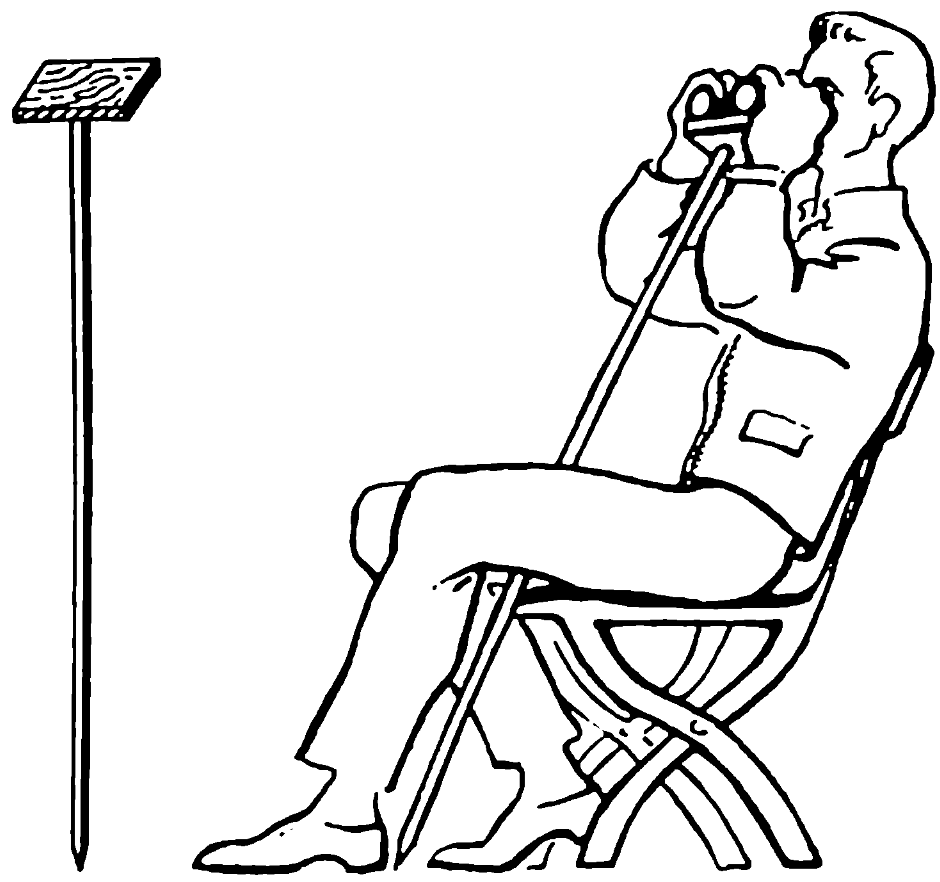


Fig. 8. A simple-type stand for a binocular.

mounting which permits of rotation about two mutually perpendicular axes: the horizontal and vertical.

Since the motion of a celestial body over the heavens involves the simultaneous variation of angular altitude above the horizon and azimuth, the altazimuth arrangement has one essential defect: it requires corrections in both altitude and azimuth.

The small school refractor permits observing stars down to the eleventh magnitude, and it resolves two stars if the angular distance between them is not less than 2.4 seconds of arc. A much improved instrument is the Maksutov meniscus school telescope, which has some advantages over ordinary refracting telescopes.

In the refractor, the objective is a positive converging lens or a system of two lenses functioning jointly as a single converging lens (Fig. 9).

The objective, gathering rays from a celestial body, produces its image in the so-called focal plane. This image is seen through a strongly magnifying compound lens system called the eyepiece.

Both the object and the eyepiece of the telescope have definite focal lengths (which is the distance from these lenses to the clear-cut images of distant objects that they yield). It can readily be proved that the magnifying power

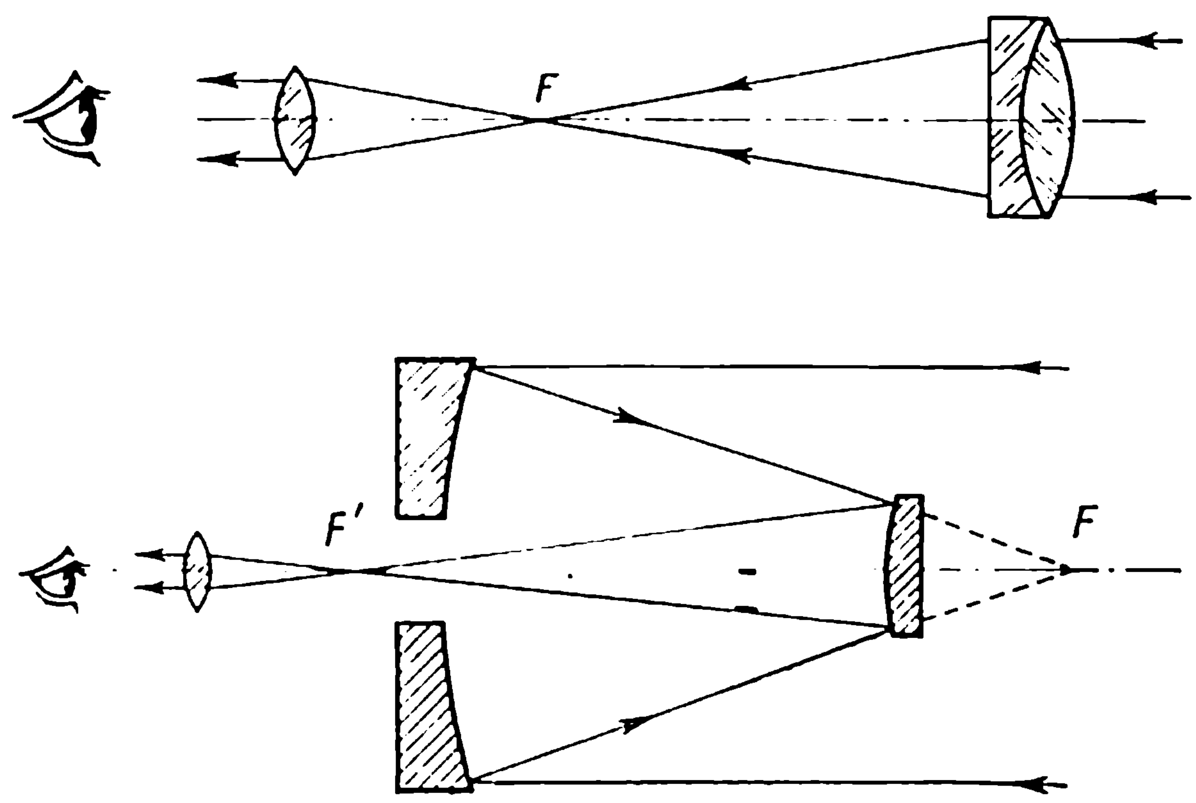


Fig. 9. Diagrams of refractor (top) and reflector (*F* stands for focus).

of a telescope is equal to the ratio of the focal length of the objective to the focal length of the eyepiece. To illustrate, if the focal length of the objective is one metre and the focal length of the eyepiece is one centimetre, the telescope will have a magnifying power of 100. In other words, in such a telescope we see all celestial bodies at an angle one hundred times greater than with the unaided eye.

In a reflecting telescope, the objective is a concave parabolic mirror. The image it produces of an astronomical body is usually reflected by means of a mirror or prism into an eyepiece at the side and mounted on the tube of the reflector. There are also reflectors that have an opening for the eyepiece in the principal mirror. The path of light rays is illustrated in Fig. 9.

Though the advantages of refracting and reflecting telescopes are many, they are not without essential shortcomings. Their optical systems (lenses and mirrors) introduce distortions, known as *aberrations*, into the images of celestial bodies. The principal distortions are *spherical* and *chromatic aberrations*.

The edges of a convergent lens refract the light rays of a parallel beam more strongly than do the central parts. For this reason, the point of convergence of the "edge" rays (their focus) is located closer to the lens than the focus of the "central" rays. This is spherical aberration, which causes a smearing of the image produced by a lens. To put it

more precisely, due to spherical aberration, either the edges of the image are smeared (out of focus) or the central portions are. And it is impossible to attain identical image definition in all its portions.

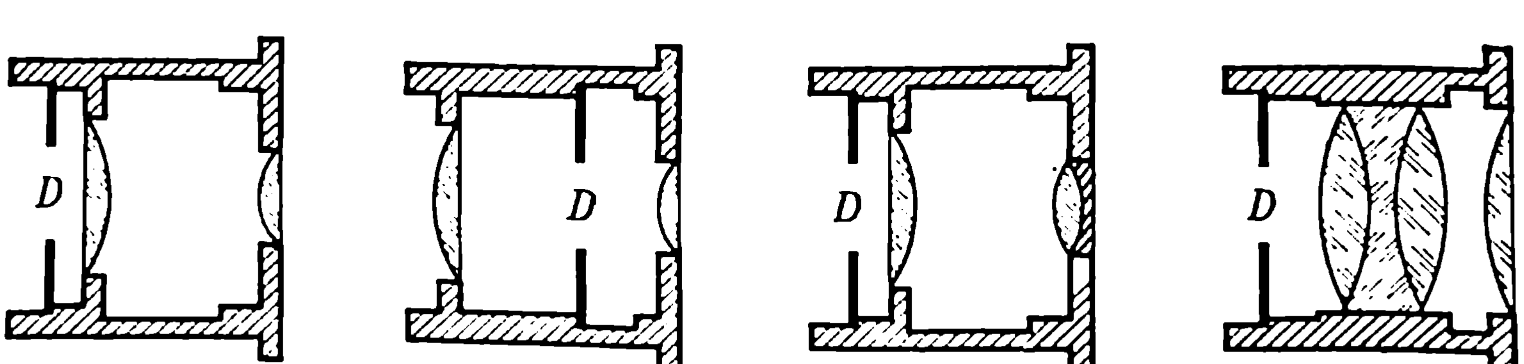
Chromatic aberration is different. It consists in the fact that rays of different colours are refracted differently by a lens: violet, for instance, more strongly than red. This makes the image of a celestial body look rainbow-coloured, which obviously hampers observations.

To diminish aberrations, refractor objectives are made up of two (sometimes three) lenses (see Fig. 9). The first lens is doubly convex, the second, planoconcave. Combined, they function as a single convergent planoconvex lens. Eyepieces are of a similar design (Fig. 10).

It is possible, by selecting the appropriate lens curvature and type of glass to have the objective of a refractor practically free from spherical aberration. However, it is not possible to completely eliminate chromatic aberration in this way; there will always remain a certain (true, continuous-tone, usually bluish) colouring of the images.

In this respect reflectors are better than refractors. Their objectives are mirrors that do not suffer from chromatic aberration, and if the primary mirror is paraboloidal, spherical aberration is greatly reduced. True, the chief difficulty lies in parabolization of the mirror, that is, making a rigorously true paraboloidal shape. The accuracy required is exceedingly great. For example, when manufacturing the mirror of the world's largest reflector for Mount Palomar (USA), which is five metres in diameter, the permissible deviations from ideal form did not exceed fractions of a micrometre!

This clearly suggests the enormous difficulties involved in making large reflecting telescopes. Making large refrac-



(a) (b) (c) (d)

Fig. 10. Different types of eyepieces:
a) Ramsden; *b*) Hyughens; *c*) Kelner (achromatic); *d*) Abbe (orthoscopic)

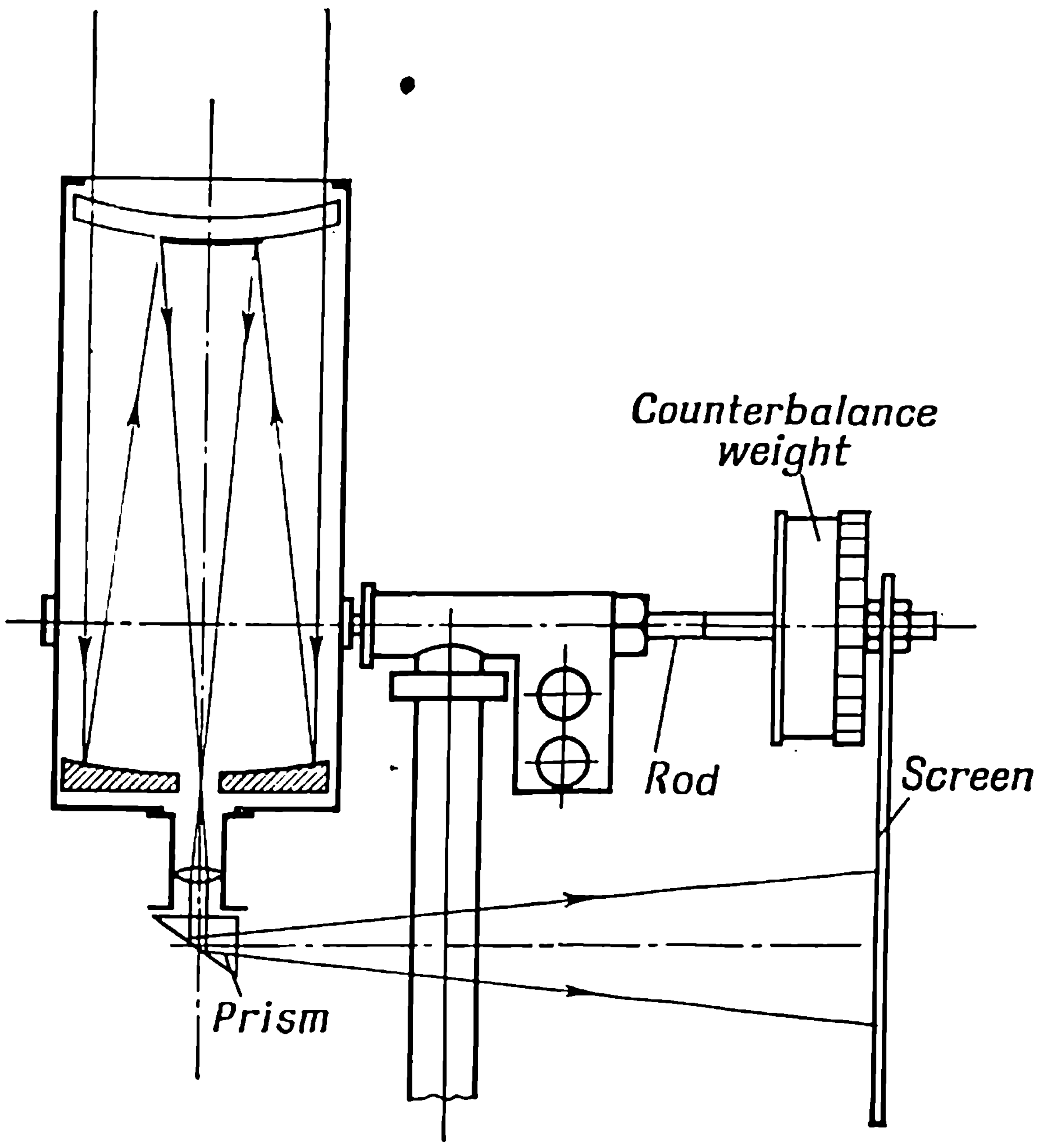


Fig. 11. School meniscus telescope (diagrammatic).

tors is not any easier. This has brought to the fore the necessity of designing new telescopic systems of relatively moderate size and high optical qualities. One such system is the meniscus telescope invented in 1941 by Corresponding Member of the USSR Academy of Sciences D. D. Maksutov. At present meniscus telescopes are widely used in the USSR and other countries. Fig. 11 is a diagrammatic scheme of a school-type meniscus telescope.

The light rays coming from a star pass through a thin convexo-concave diverging lens (meniscus) before entering the principal concave mirror of the telescope. The rays are then reflected from the principal mirror and again enter the meniscus lens, the central part of the inner surface of which is silvered and thus plays the part of a convex mirror, from which the rays are reflected and then enter an eyepiece inserted in the opening of the principal mirror.

Such, in outline, is the diagram of a meniscus telescope. Its advantages are very essential.

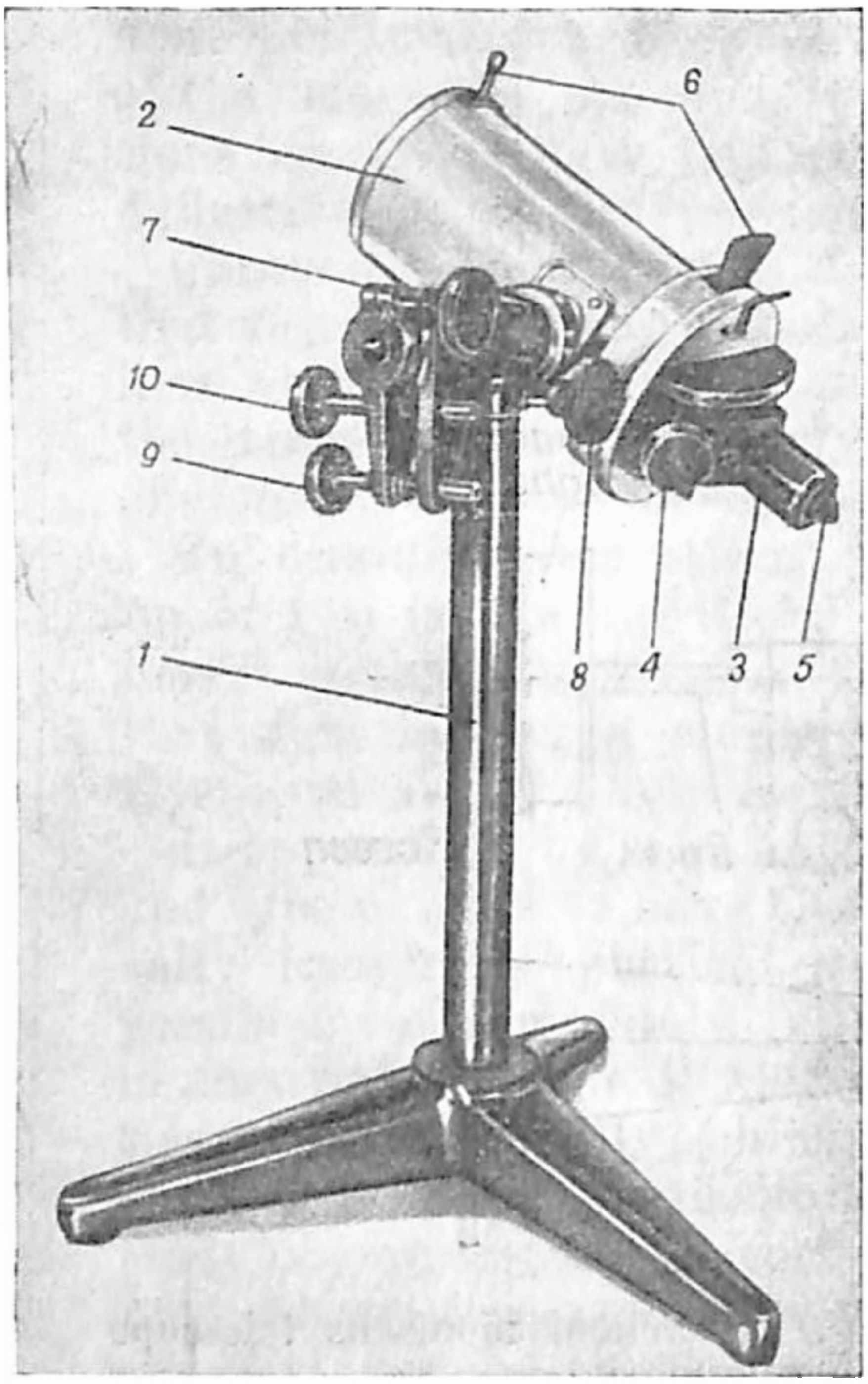


Fig. 12. School-type meniscus telescope:
1—stand; 2—tube; 3—25× eyepiece; 4—70× eyepiece; 5—zenith prism; 6—sights for choosing object; 7-10—clamp screws and fine-focussing screws.

First of all, and this is the main idea of the meniscus telescope, the surface shape of the meniscus may be chosen so that for a spherical surface of the principal mirror the spherical aberration of the meniscus completely compensates for (or eliminates) the spherical aberration of the mirror. On the other hand, due to the thinness of the meniscus and its slight curvature, chromatic aberration is practically nonexistent. In this way, a meniscus telescope yields clear-cut uncoloured high-quality images.

Secondly, the optical system of meniscus telescopes requires much less effort to manufacture than do conventional reflectors. This is due to the fact that both the principal mirror and the meniscus have spherical surfaces, and this is a technical advantage over the more difficult parabolic surface.

Thirdly, a light ray changes direction twice in a meniscus telescope, thus greatly reducing the length of the instrument and making it more compact and convenient to handle.

Finally, the meniscus hermetically seals the tube of the telescope, thus protecting the principal mirror from moisture and dust, which lengthens its lifetime.

A school-type meniscus telescope (Fig. 12) is very compact: tube length, 25 cm, height together with stand, only 40 cm. This telescope can reach to stars of the eleventh magnitude and has a higher resolving power than the small school refractor (about two seconds of arc).

The rotating set of two eyepieces offers magnifications of 25 and 70. Both are equipped with zenithal prisms that simplify observations of stars close to the zenith. The

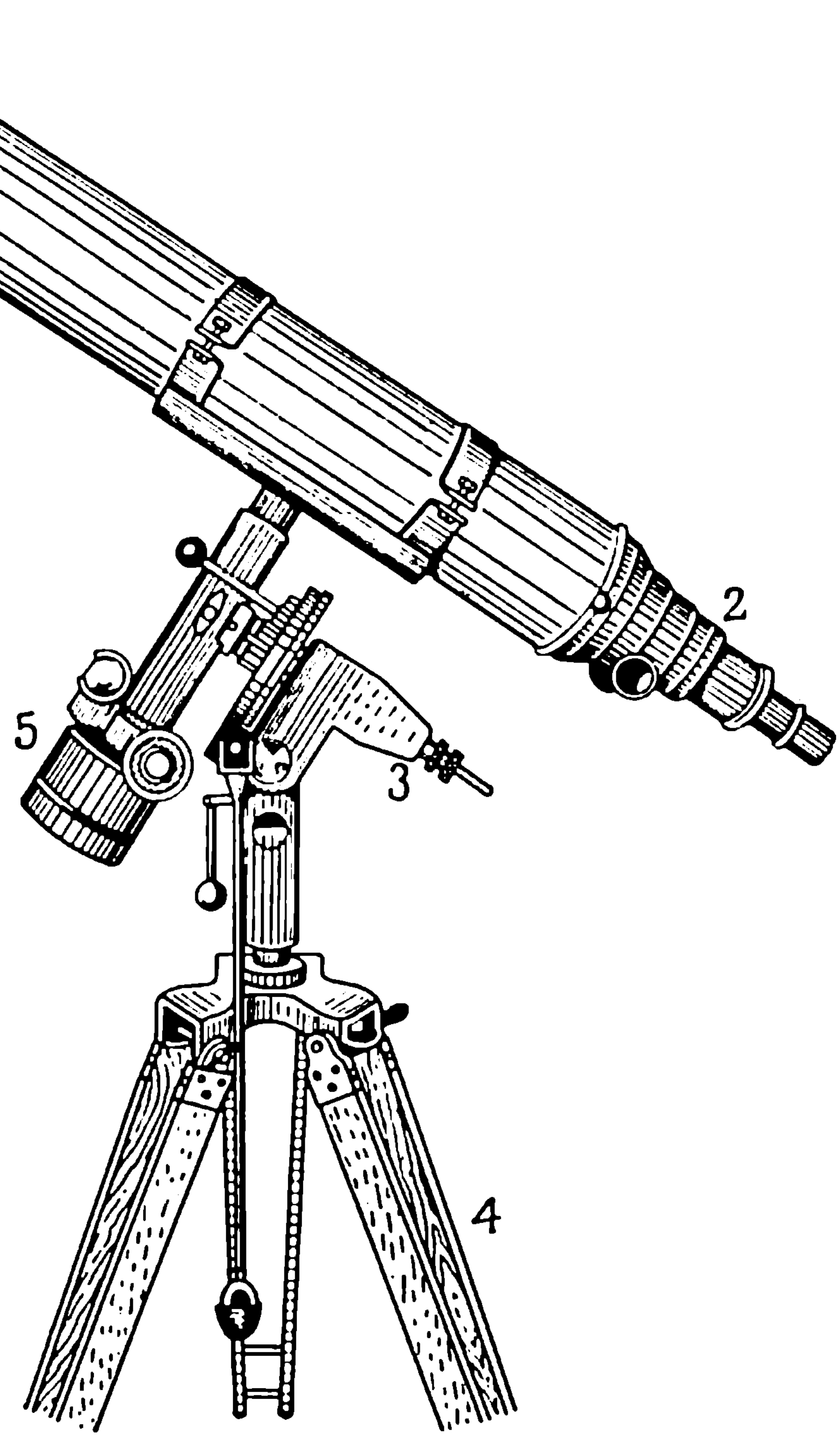


Fig. 13. Big school refractor:
1—tube; *2*—eyepiece; *3*—mounting; *4*—stand; *5*—counterbalance weight.

sighting device is convenient for training the telescope on a given object.

The mounting of this meniscus telescope is altazimuth, which is a drawback. True, the altazimuth head of the instrument is equipped with a clamp screw and also micrometer screw, which enable the observer to move the telescope slowly in order to follow a star as it moves out of the field of view. But this is really of little help.

Another inconvenience is the short instrument stand. This makes it necessary to provide added support in the form of a table, or a special pillar.

The instrument has a large field of view. At 25 power its diameter is equal to 48 minutes of arc, at 70 power, 16 minutes of arc, which is nearly half the apparent lunar disc.

Despite these shortcomings, the school-type meniscus telescope has fairly decent optical qualities and the instrument may be recommended for studies of the stellar sky.

The best of all school instruments is undoubtedly the *large school refractor* (Fig. 13) with 80-mm objective. First of all, its mounting is parallactic (equatorial) and not altazimuth. In this mounting, one of the two mutually perpendicular axes about which the telescope turns is directed at the celestial pole (or, approximately, at the Pole Star). For this reason, when revolving about the other axis, the telescope follows the star, and to hold the object in the field of view of the instrument, it is sufficient to use the so-called hour screw. The parallactic mounting of the instrument (which is removable) is connected with a high, collapsible tripod. This is particularly convenient for the observer.

We omit detailed design descriptions (as in the other cases) and point out that the large school refractor has all the features of a real telescope: a counterbalance weight on the declination axis, two clamp screws and two micrometer screws, a device for setting to the latitude of the place of observation, and many other features. The telescope is equipped with a diaphragm and a special light-filter for solar observations. But we are interested in the features of this instrument that are directly related to observations of the night sky.

The diameter of its objective is 80 mm. It has three eyepieces 80, 40 and 28.5 power. On nights when the seeing is good, it resolves stars down to magnitude 11.5.

The theoretical resolving power of the large school refractor is 1″.75. The practically obtainable power is a little lower, for reasons given above: 2″.06.

All three school telescopes are not only excellent instruments for getting a general acquaintance with the constellations, but are also quite suitable for certain of the simpler scientific observations. Whoever is inclined to pass on from a general inspection of celestial bodies to their scientific study (which is extremely desirable) will have to take up the special literature.

A few points about how to begin are in order at this stage.

The hardest thing for the beginner is to train his telescope on the object of interest. The only solution is training and practice, and some experience in aiming the telescope at terrestrial objects. When directing it, look along the tube of the telescope and when the object is on the end of the upper part of the tube, turn the telescope so that the lateral surface of the tube passes out of view. Then look into the eyepiece and you will see the object. Tighten the clamp screw and then bring the image to a sharp focus.

It is advisable from the very start to make a mark on the eyepiece tube of the telescope of the position of clear-cut focus of the various eyepieces. If the eyepiece has not been focussed beforehand, it is very difficult and sometimes impossible to detect a faint star or nebula even when the instrument is accurately trained.

In a telescope, bright stars are not seen as points but as tiny discs. Do not think that you are viewing the actual discs. The stars are so far away from the earth that even the largest terrestrial telescopes do not enable us to view stellar discs. The apparent stellar discs are a consequence of a specific optical phenomenon known as diffraction. The greater the diameter of the objective of the telescope, the smaller the deceptive diffraction disc. Under good atmospheric conditions, the diffraction disc of a star is surrounded by several bright diffraction rings, which are optical formations that naturally have nothing to do with the star itself.

Different magnifications are used for different objects. Nebulae and star clusters are ordinarily more convenient to view with low-power eyepieces. And conversely, to separate close-lying and sufficiently bright double stars,

it is best to use a high-power eyepiece. The best practice, when training the telescope on an astronomical body is to first use a low-power eyepiece, and then change over to a high-power one when the body is in the field of view. The greater the power of the eyepiece, the smaller the diameter of the field. For this reason, only experienced observers can train a powerful telescope straight off.

When observing particularly faint objects, try the technique of "averted vision". This is frequently done when examining nebulae. Remember that the best images are obtained when the object is brought into the centre of the field of view because here the aberration of the instrument is much smaller than at the edges.

The programme of observations described in this book is within the range of the large school refractor telescope. This maximum programme may be used (with appropriate amendments) when observing with other instruments.

WHERE AND WHEN?

Let us say you have decided to start astronomical observations. The object of observation has been selected, the night is clear, there is only one thing left: Where is the object to be found?

The earth is spherical in shape and participates in two kinds of motion: it rotates on its axis and revolves about the sun. For these reasons, the night sky, or more precisely, the apparent positions of the stars across the sky with respect to the horizon depend mainly on three circumstances: the position of the observer on the earth, the time and the calendar date. All of which means that one cannot answer the question about the position of an object in the sky if he does not know when the observations are to take place. Let us again stress the fact that the position of the observer on the earth (more precisely, the geographic latitude of the site of observation) is assumed to be known. To get a better understanding of all these problems (and this is necessary for dealing with star maps), let us examine in general outline some of the more important concepts of *spherical astronomy*.

The simplest astronomical phenomena that occur in the heavens are familiar to everyone from childhood. The sun and moon are in motion across the sky, thousands of stars come out at night, and, to the chagrin of astronomers, the sky is quite often overcast.

The word "sky" itself needs to be rigorously defined, for it is so often used by astronomers. When we are in an open place like a field or at sea, the whole world appears divided into two parts: the earth's surface under us and the heavenly dome or sky above. Thus, *the sky is that part of space seen through the earth's atmospheric mantle.*

The terrestrial atmosphere gives a somewhat distorted picture of the cosmos. Firstly, cloud formations hamper astronomical observations to a greater or lesser extent. Secondly, of all rays coming to the earth from the sun, the atmosphere subjects the blue rays to the greatest scattering. That is why the sky is blue in clear weather. Without the mantle of air, our sky would be jet black day and night. Thirdly, and lastly, the air mantle of the earth alters the direction of light rays coming from celestial bodies, attenuates them (via absorption) and even modifies their colour. That, for one thing, is why the stars seem to twinkle in all the colours of the rainbow.

All these distortions are still not so great; on the whole, in fact, we can say that the terrestrial atmosphere is highly transparent (to the visible portion of the spectrum, that is).

The sky always appears as a nearly spherical dome resting round the fringes on the earth's surface. This illusion suggested to the ancients the idea of a "celestial firmament" (celestial sphere) or a solid vault of the heavens. The term persists, yet nobody seriously takes it in the original meaning of something solid. We shall regard it to mean the optical illusion of a celestial dome.

Another illusion is the lack of any feeling of difference in distances to the sun, moon, and stars. All celestial bodies appear to us to be at an equal distance away and moving over the same celestial sphere.

For this reason, when astronomers consider events in the sky, they conveniently picture a sphere of arbitrary radius with centre in the eye of the observer, and on the surface of which are projected the images of the celestial bodies. This arbitrary sphere is termed the *celestial sphere*.

In some cases the centre of the celestial sphere is made to coincide (mentally) with the eye of an imaginary observer located, say, at the centre of the sun or at some other point of the universe.

The celestial sphere is of course not an actual structure but a conjectured geometric construction introduced for the convenience of measuring the apparent positions of astronomical bodies.

The radius of the celestial sphere is taken to be arbitrary (and not necessarily very large) for the simple reason that distances to astronomical bodies are of no importance at this early stage of observations and we confine ourselves

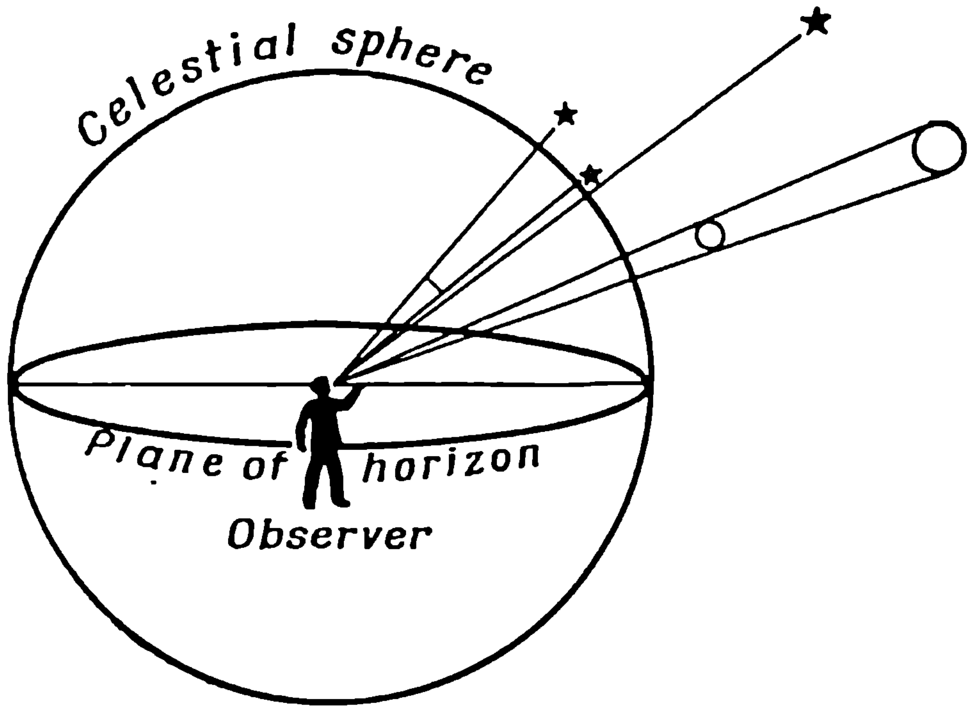


Fig. 14. The celestial sphere.

solely to angular measurements. You will recall that angles are indifferent to the lengths of the sides, the size of the angle remaining the same in all cases. Now imagine an observer located on the surface of the earth and a celestial sphere described around him (Fig. 14). At every spot on the earth, a plumb line will determine the vertical line, which will intersect the celestial sphere in two points Z and Z' (Fig. 15). The point directly overhead is the *zenith* (Z) and the opposite point is the *nadir* (Z').

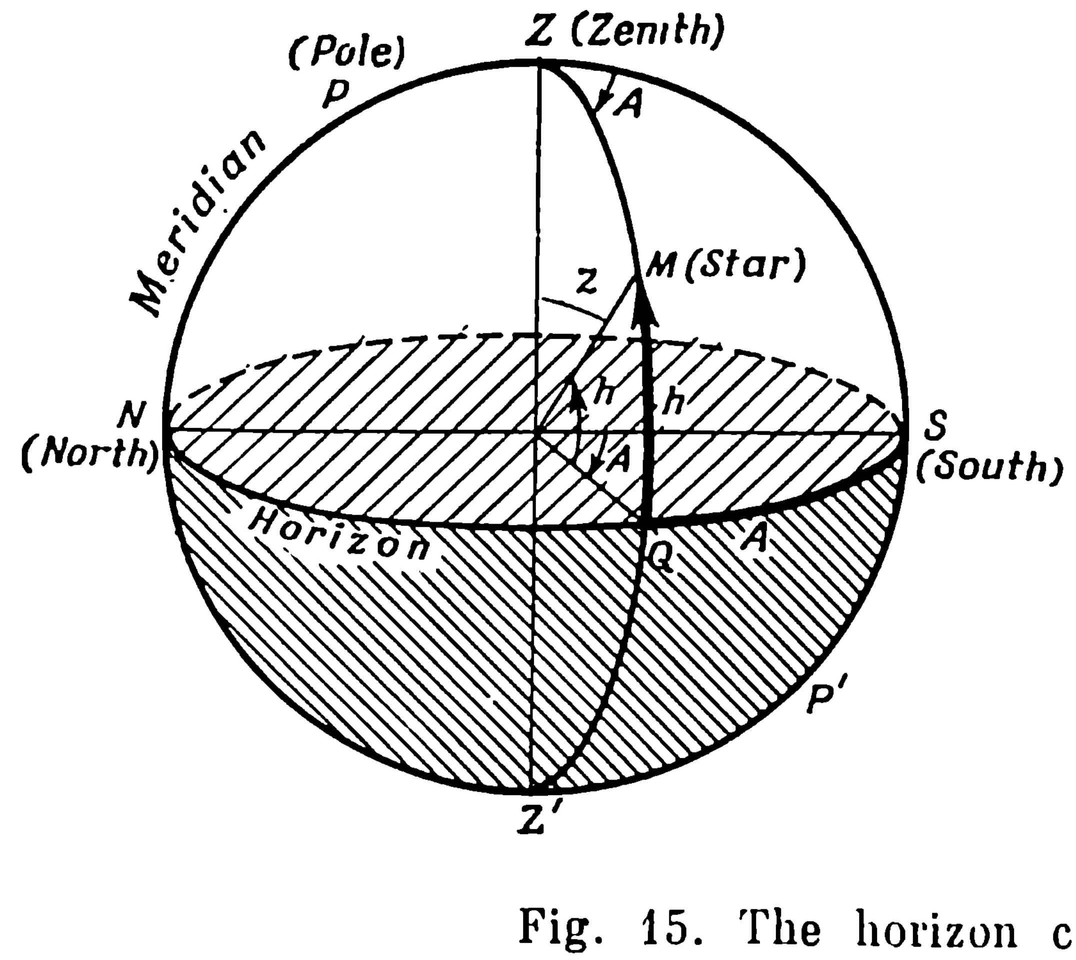


Fig. 15. The horizon coordinate system.

Fig. 16. Diurnal motion of stars in the circumpolar region.

Let us pass a horizontal plane through the centre of the celestial sphere (the eye of the observer). The circle produced by the intersection of this plane and the celestial sphere is called the *celestial* or *mathematical horizon.*

It is quite easy to see that the mathematical horizon does not coincide with the *visible* or *observed horizon.* The latter consists of points at which the line of sight of the observer touches the earth's surface. Since the plane of the mathematical horizon is located above the earth's surface, that horizon will always be somewhat "raised" above the visible horizon.

To simplify our drawings we shall not picture the earth or the observer any more in figures containing the celestial sphere. We will presume their existence every time.

The new terms, vertical line and mathematical horizon, now enable us to comprehend better the more elementary of the apparent motions of the celestial bodies, say the stars.

It is common knowledge that the daily motion of the sun over the sky is an illusion. Actually, the earth itself is in nearly uniform rotation and its rotation is the cause of the periodic change of day and night.

The earth's rotation generates the apparent diurnal movement not only of the sun but of all other celestial bodies as well. This is obvious from a few simple observations.

When the sun goes down below the horizon and the stars come out, note some bright star in the southern part of the sky. Note its position with respect to some object on the earth, then repeat the same observation at the same spot in half an hour or so. You will see that the star has shifted its place on the sphere. It is not difficult to check any other star as well for the same displacement on the celestial sphere. Consequently, the entire night sky appears to be revolving about the earth.

Now take a camera, set the objective lens at "infinity"; fixed stationary, point it to the northern part of the night sky that contains the Pole Star (Polaris). Now take a photograph with a one-hour exposure. Due to their apparent motions, the stars will describe concentric arcs, the centre of which is close to Polaris (Fig. 16).

Thus, we seem to have found a fixed point on the celestial sphere, about which all observable stars appear to revolve. This point is called the *north celestial pole*. A similar fixed point on the opposite side of the celestial sphere is the *south celestial pole* (Fig. 17). The straight line connecting the two poles is known as the *celestial axis*. When observing the night sky, one gets the false impression that all the stars are attached to an invisible transparent crystal-like sphere (that was how the ancients pictured it) and that this sphere is in slow rotation about the celestial axis, executing one complete circuit every 24-hour period.

If through the centre of the celestial sphere we pass a plane perpendicular to the celestial axis, it will cut the celestial sphere in a line called the *celestial equator*. The celestial equator divides the sky into two hemispheres. The one with the Pole Star is the northern hemisphere, the other one, the southern. It is not difficult to realize that the celestial equator has the same radius as the celestial sphere. Circles of this kind on the surface of any sphere are called the *great circles* of the sphere.

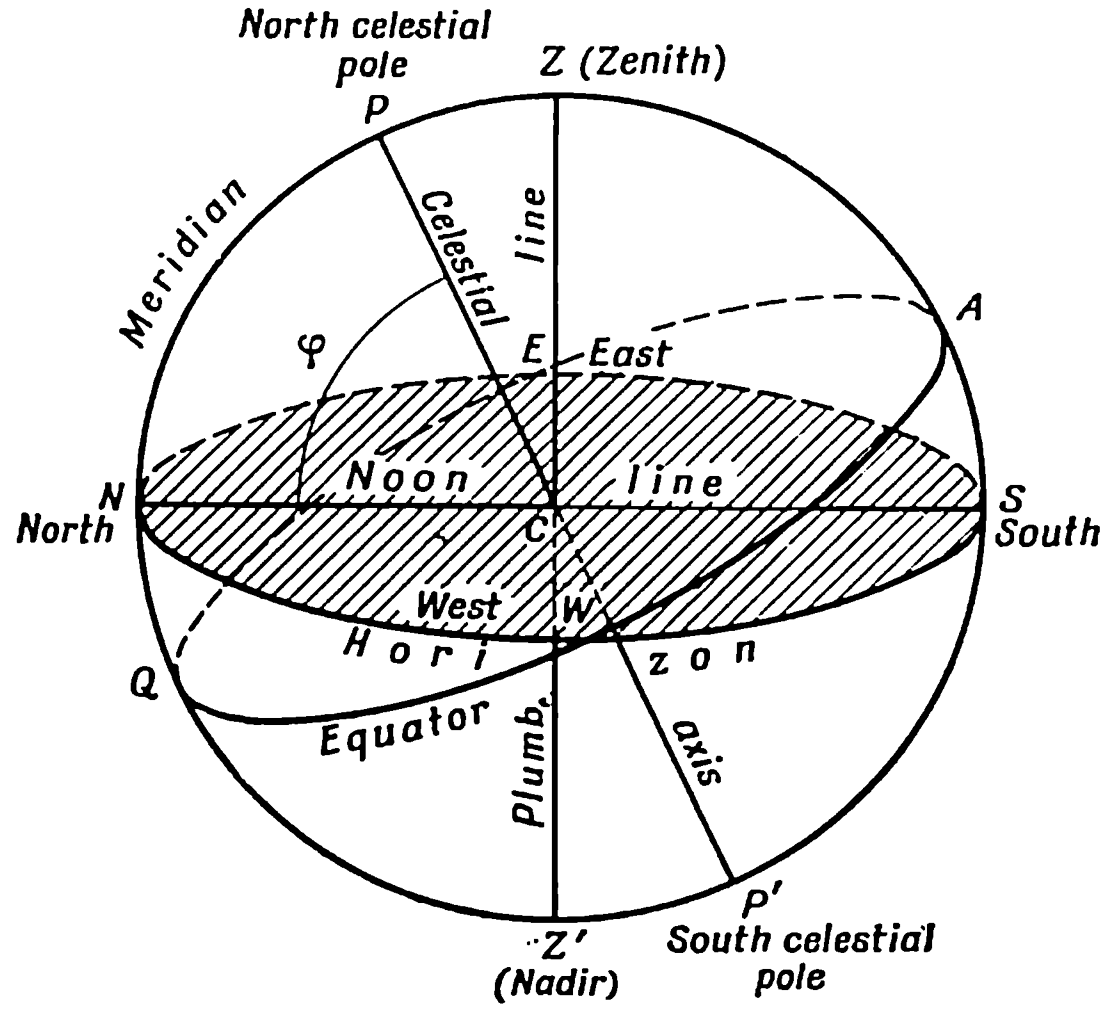


Fig. 17. Celestial equator and celestial meridian.

The apparent paths of the stars in their apparent movements over the celestial sphere are parallel to the celestial equator. The same also goes for the apparent diurnal paths of the sun and moon.

Let us mentally draw a plane through three points: the eye of the observer, the zenith, and the north celestial pole. It will cut the celestial sphere in a great circle, which is called the *celestial meridian*. The celestial meridian intersects the mathematical horizon in two points, the one closer to the north celestial pole being the *north point*, and the opposite one, the *south point*. The points of the horizon at 90° angles to these are known as the *east point* and the *west point*. Obviously, the celestial equator cuts the mathematical horizon precisely in these points.

The straight line connecting the north and south points is the *noon line*. It will readily be seen that at noon, the shadows cast by all objects fall in the direction of this line.

Observing the apparent motion of the stars in the southern part of the heavens, we note that when they cross the celestial meridian they occupy the highest position above the horizon. Conversely, on the section of the celestial meridian between the north celestial pole and the north

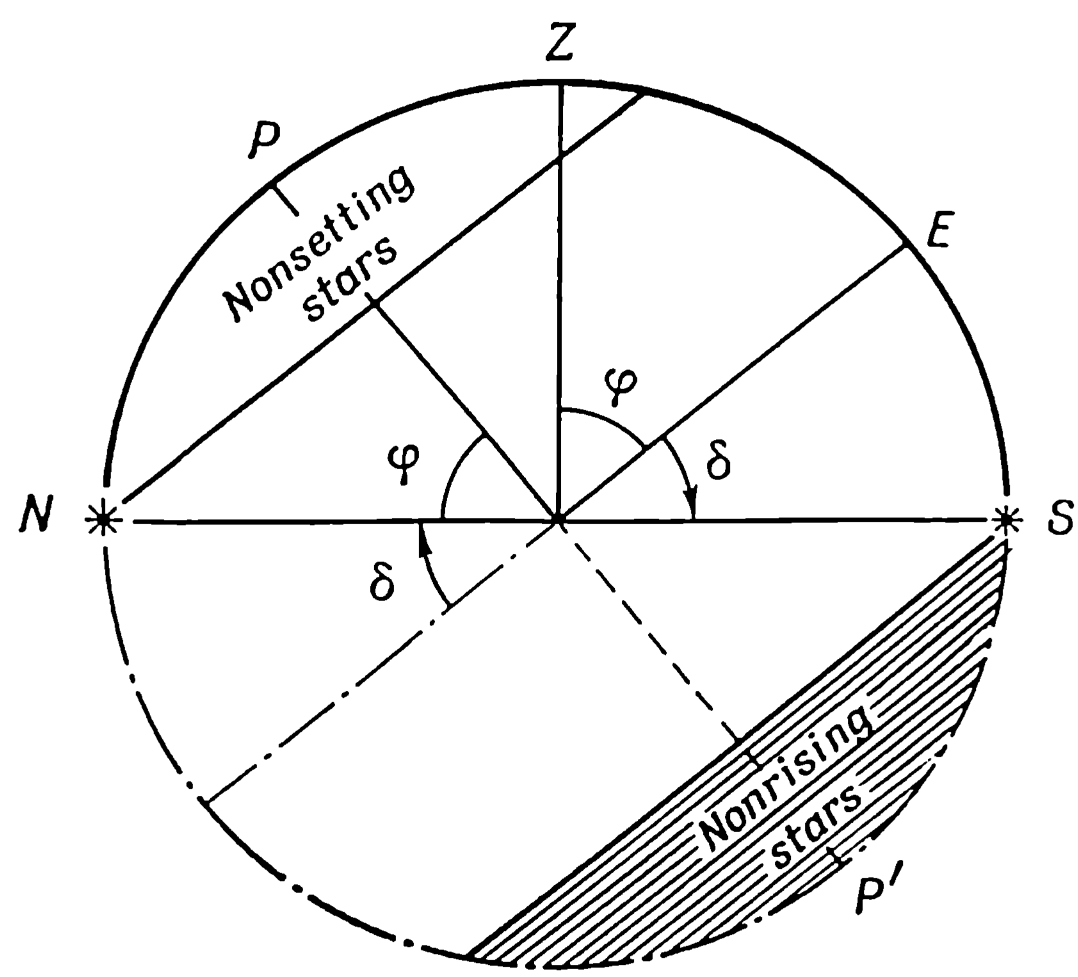


Fig. 18. Nonsetting and nonrising stars.

point, a star crossing the celestial meridian will be in its lowest position with respect to the horizon. The former occurrence is termed *upper transit* of a star (or any other astronomical body, for that matter), the latter is the *lower transit* of the body.

Thus *transit* (or *culmination*) *of a body is its passage across the celestial meridian* (also termed *meridian passage*).

Continuing observations of the night sky, we note that the stars (for an observer in moderate latitudes of the northern hemisphere) may be divided into three groups. In the first group are those which in lower transit pass above the north point. Quite obviously, they never cut the line of the horizon and therefore form a group of *nonsetting stars* (Fig. 18).

Then there are stars whose upper transit occurs below the horizon, below the south point. They belong in the group of *nonrising stars*.

Finally, between these two zones of the sky is a region in which all stars cut the line of the horizon twice every 24 hours (at setting and rising time). They form the group of *rising* and *setting stars*.

It has already been mentioned that all stars in their apparent diurnal motion (due to the axial rotation of the

earth) move over the celestial sphere parallel to the celestial equator. Since the angular distance of any star from the celestial equator is a constant, it is natural to fix the place of a star on the celestial sphere relative to the celestial equator and to the horizon. The angular distance of a star from the celestial equator is denoted by the Greek letter δ, and is called the *declination* of that body.

Thus, *the declination of an astronomical body is the angle between the direction from the centre of the celestial sphere to the given body and the plane of the celestial equator.*

The semicircles connecting the celestial poles are called *declination circles*. One of these circles always passes through a given body.

Declination is measured in degrees, minutes and seconds of arc. It has been agreed to call the declination positive for bodies lying in the northern hemisphere of the sky, and negative for bodies in the southern hemisphere. This immediately suggests that all points of the celestial equator have zero declination and the celestial poles have declination $+90°$ (north pole) and $-90°$ (south pole).

The declination alone cannot fully describe the place of a body on the celestial sphere. We must have a second coordinate which together with the declination will uniquely fix the position of a body on the celestial sphere.

This second coordinate is known to astronomers as the *right ascension* α. Let us see how it is determined.

There is a point on the celestial equator at which the sun arrives every year on the day of the spring equinox, March 21. This point, called the *point of the vernal equinox* (*the first point of Aries*), is taken as the reference origin in the equatorial system of coordinates. It is designated by the conventional symbol ♈ (which should not be confused with the Greek letter gamma, γ).

Let us draw a declination circle through the celestial poles and a given body. As will be seen from Fig. 19, the right ascension of the body (α) is equal to the angle between the direction from the centre of the celestial sphere to the point of the vernal equinox and the plane of the declination circle of the given body.

The right ascension of the body is reckoned counterclockwise when looking from the north celestial pole.

Although right ascension (like declination) is an angle, it is more convenient, for a number of reasons, to measure

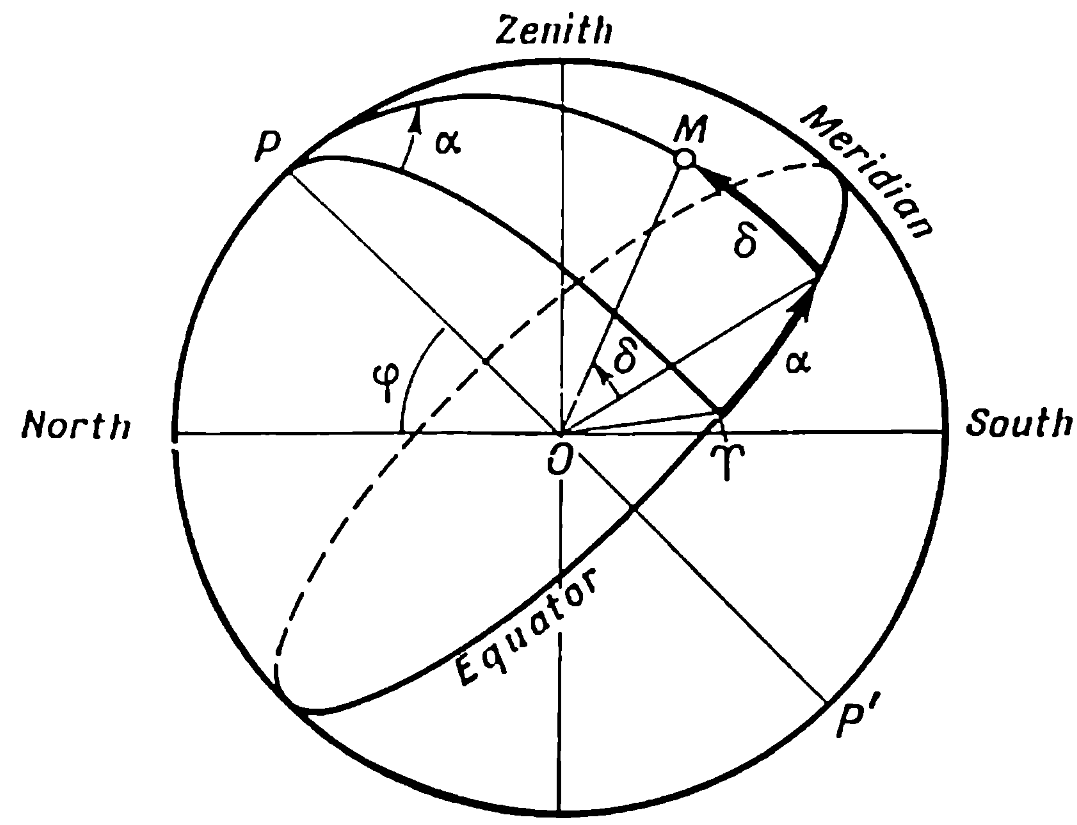


Fig. 19. Equatorial coordinate system.

it in units of time than in degrees, minutes and seconds of arc.

Since the celestial sphere executes a full circuit in 24 hours as it revolves about the observer, it follows that an angle of 360 degrees is equal to 24 hours of time. Hence, every hour equals 15 degrees, and every degree equals 4 minutes of time.

The following is a table with time and arc units correlated:

360°	equals 24 hours of time
15°	equals 1 hour of time
1°	equals 4 minutes of time
15′	equals 1 minute of time
1′	equals 4 seconds of time

The abbreviated notation of right ascension for hours, minutes and seconds is h, m, s: 5h 12m 6s.

The right ascension and declination of a celestial body are known as its celestial *equatorial coordinates.*

Celestial equatorial coordinates are much like the geographic coordinates, right ascension corresponding to longitude and declination to latitude. The geographic coordinates can also be called equatorial, since they are defined with reference to the terrestrial equator.

Just as the latitude and longitude of cities of the earth remain the same as the earth rotates, so diurnal rotation of the celestial sphere does not change the declination and

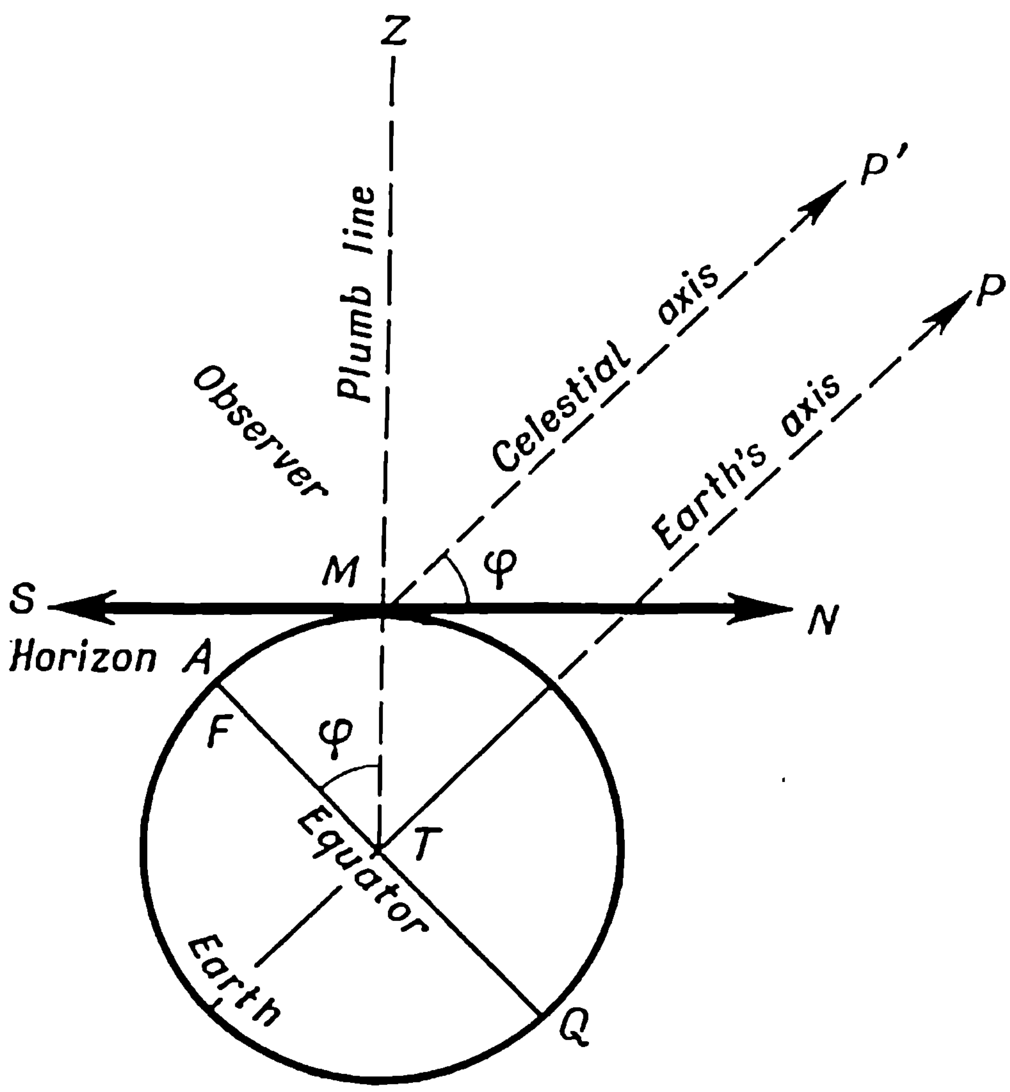


Fig. 20. Theorem on the altitude of the celestial pole.

right ascension of the stars. Star catalogues containing information about the various stars also indicate their equatorial coordinates. Now the "wandering bodies" of the heavens (sun, moon, planets, and others) are different. Their right ascensions and declinations are naturally constantly undergoing change, just like the geographic coordinates of travellers on the earth.

Geographic maps have coordinate grids of meridians and parallels. So also do maps of the stellar sky.

When travelling along a geographic meridian it will readily be seen that the angular altitude of the Pole Star above the horizon does not remain constant, diminishing as we move south. The Pole Star gradually approaches the horizon. Just the opposite occurs when we move northwards: the Pole Star approaches the zenith.

The altitude above the horizon of the north celestial pole with Polaris nearby behaves in a similar manner. We can easily prove that the altitude of the north celestial pole above the horizon is always equal to the geographic latitude of that place on the earth.

We refer to Fig. 20, which depicts the earth. At any

point on the earth, the celestial axis is parallel to the earth's axis and therefore the altitude of the celestial pole and the geographic latitude of a given place are angles with mutually perpendicular sides (the celestial axis is always perpendicular to the plane of the terrestrial equator, while the earth's radius drawn to the point of observation is perpendicular to the tangent horizontal plane).

These angles are therefore equal, which means that the altitude of the north celestial pole is equal to the geographic latitude of the given place.

From this it inevitably follows that in different latitudes the night sky and the apparent motions of the celestial bodies appear substantially different.

We have already learned about the night sky and the movements of celestial bodies in moderate latitudes. Let us now see how the picture changes as we move to the north pole and to the terrestrial equator.

As we move northwards, the altitude of the celestial pole and Polaris will constantly be on the increase. When we arrive at the north pole of the earth, the north celestial pole will coincide with the zenith, and the celestial equator with the horizon. Then the altitude of the celestial pole will be 90°, or equal to the geographic latitude of the earth's north pole.

Since in their apparent diurnal motions, the stars move parallel to the celestial equator, at the north pole of the earth they will be in motion parallel to the horizon. Here there are no stars that rise and set. At the north pole, all stars of the northern hemisphere of the sky are nonsetting stars, and in the southern hemisphere of the sky, nonrising stars.

At the north pole of the earth, the concept of points on the horizon is meaningless. Here, every direction is south and along some meridian. We cannot speak of the transits of stars because their altitudes remain the same throughout the 24-hour period.

The picture is the same at the south pole of the earth, at the centre of Antarctica. We will see only stars of the southern hemisphere of the sky, and the south celestial pole will coincide with the zenith. However, here too, all stars during a rotation of the earth will describe circles on the celestial sphere parallel to the horizon.

The picture will be different on the terrestrial equator.

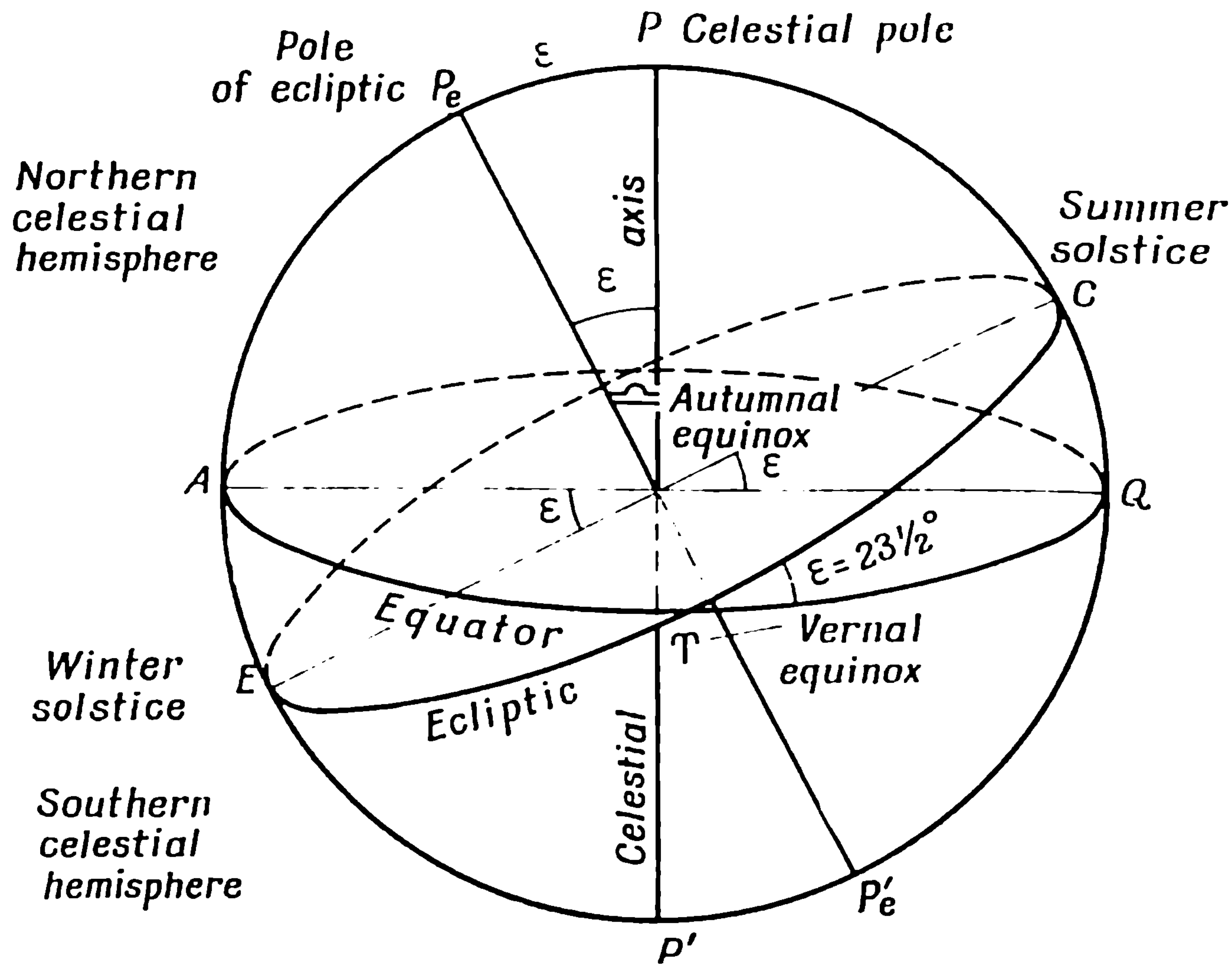
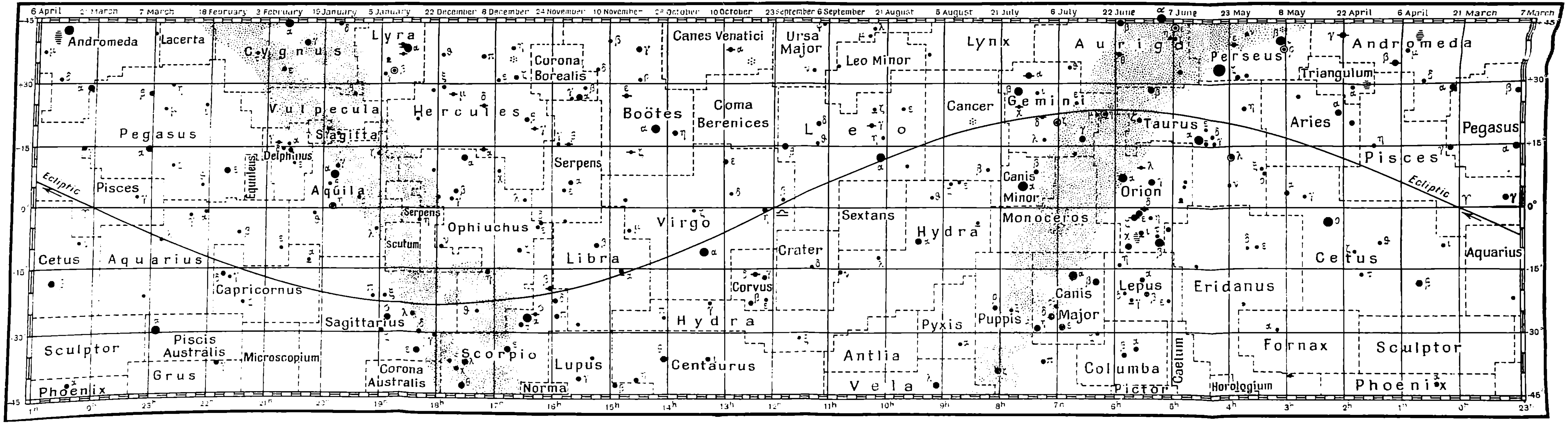


Fig. 21. Celestial equator and the ecliptic.

The geographic latitude of all its points is zero. Hence, the altitude of the north celestial pole should also be zero for the observer. Thus, on the terrestrial equator the celestial poles coincide with the north and south points, and the celestial axis lies in a horizontal plane coinciding with the noon line. Here the celestial equator passes through the zenith, and its plane is perpendicular to the plane of the horizon. Whence it follows that all stars (for an observer on the terrestrial equator) will be moving in circles whose planes are perpendicular to the horizontal plane. There are no non-rising stars on the earth's equator. All stars cross the line of the horizon twice a day, and if the sun weren't there, the whole stellar sky would be observable during a 24-hour period.

The earth moves round the sun and for this reason the sun is projected on different portions of the stellar sky at different times of the year in observations from the earth. This is how we get another illusion caused by the revolution of the earth round the sun: the apparent annual motion of the sun on the stellar background.

The path of the sun across the background of constellations is known as the *ecliptic* (Fig. 21). The ecliptic is a cir-



Stars of the Equatorial Zone

period.

The earth moves round the sun and for this reason the sun is projected on different portions of the stellar sky at different times of the year in observations from the earth. This is how we get another illusion caused by the revolution of the earth round the sun: the apparent annual motion of the sun on the stellar background.

The path of the sun across the background of constellations is known as the *ecliptic* (Fig. 21). The ecliptic is a cir-

cle that cuts the celestial equator at an angle of $23^1/_2$ degrees. The points of intersection of the celestial equator and the ecliptic are called the point of the vernal equinox (symbol: ♈) and the point of the autumnal equinox (symbol: ♎). The points of summer and winter solstice lie on the ecliptic 90° to either side of the equinoctial points.

The relative configuration of the ecliptic and the celestial equator changes so gradually that in most cases it may be considered stable. Also fixed relative to the stars (to a first approximation) is the point of the vernal equinox. In other words, this imaginary point in the sky behaves like any other star: it rises, sets and transits.

The belt of the ecliptic passes through 12 constellations, which are called *zodiacal* constellations: Pisces, Aries, Taurus, Gemini, Cancer, Leo, Virgo, Libra, Scorpio, Sagittarius, Capricorn, and Aquarius.* Most of these constellations have the names of animals. That is why the ancients gave this belt the name zodiac, which means "belt of animals".

Due to the annual motion of the sun among the constellations, the night sky is constantly changing its appearance during the year. A constellation which at the present time contains the sun (to put it more precisely, onto which it is projected from the earth), is not accessible to observation, since it rises and sets together with the sun, transiting at noon. A constellation opposite to the sun (say Scorpio in December), on the contrary, is nicely visible the whole night and transits at midnight. At the top of the map in Appendix VII are dates which correspond to the position of the sun on the ecliptic at the time.

Since the sun is in constant motion along the ecliptic, different constellations will transit at midnight in different months of the year. That is why in summer we see certain constellations (with the exception of the nonsetting ones) and in winter others. As the sun journeys over the stellar sky it blots out one constellation after the other, as it were. After a time, the sun returns to its initial point in the ecliptic and the cycle of familiar changes starts up once again. During the same time, the earth completes one full orbit about the sun.

* There is a thirteenth, nonzodiacal, constellation that includes a portion of the ecliptic. It is Ophiuchus.

Now, after this brief excursion into spherical astronomy, star maps and catalogues will be much easier to understand.

To get an initial general picture of the constellations it is convenient to use a moving star chart that is put out by some planetariums.

A moving star chart gives the pattern of the night sky for any time of the year. But don't forget that the figures of the constellations on a map are somewhat distorted due to projection of the sphere on a plane.

A star chart has the ecliptic in the form of an eccentric circle cutting the equator.

For more details, the reader will find at the end of the book a small star atlas made up of five maps, which indicate stars down to the fifth magnitude and most of the sights discussed in this book. Some objects not given on these maps are indicated on charts of sections of the sky that accompany descriptions of the appropriate constellations.

More detailed star atlases will be needed for a deeper study of the constellations.

Up till now we have stressed that the equatorial coordinates of stars (their right ascension and declination) do not change. Actually, that is not exactly so: the equatorial coordinates of stars do undergo a slow constant change. This is due to a special motion of the earth's axis called *precession*.

It is a well established fact that our planet is a sphere only to a rough approximation. Actually, the earth is slightly flattened at the poles and elongated in the equatorial zone. To put it scientifically, the earth, to a second approximation, must be considered a *spheroid*, which is a solid generated by rotation of an ellipse about its minor axis.

The earth's axis is inclined to the plane of the orbit at $66^1/_2$ degrees, and the sun pulling on the earth's equatorial bulge strives to turn the earth, as it were, and make the earth's axis perpendicular to the plane of the orbit. This the sun is not able to do because the earth is in rotation about its axis. Precession is due to the turning action of the sun and the axial rotation of the earth. It is a slow cone-shaped motion of the earth's axis.

Precession is a complicated phenomenon, and many very important particulars have been left out of our brief explanatory note on the subject. The important thing for us to know at this stage is that precession alters the position of

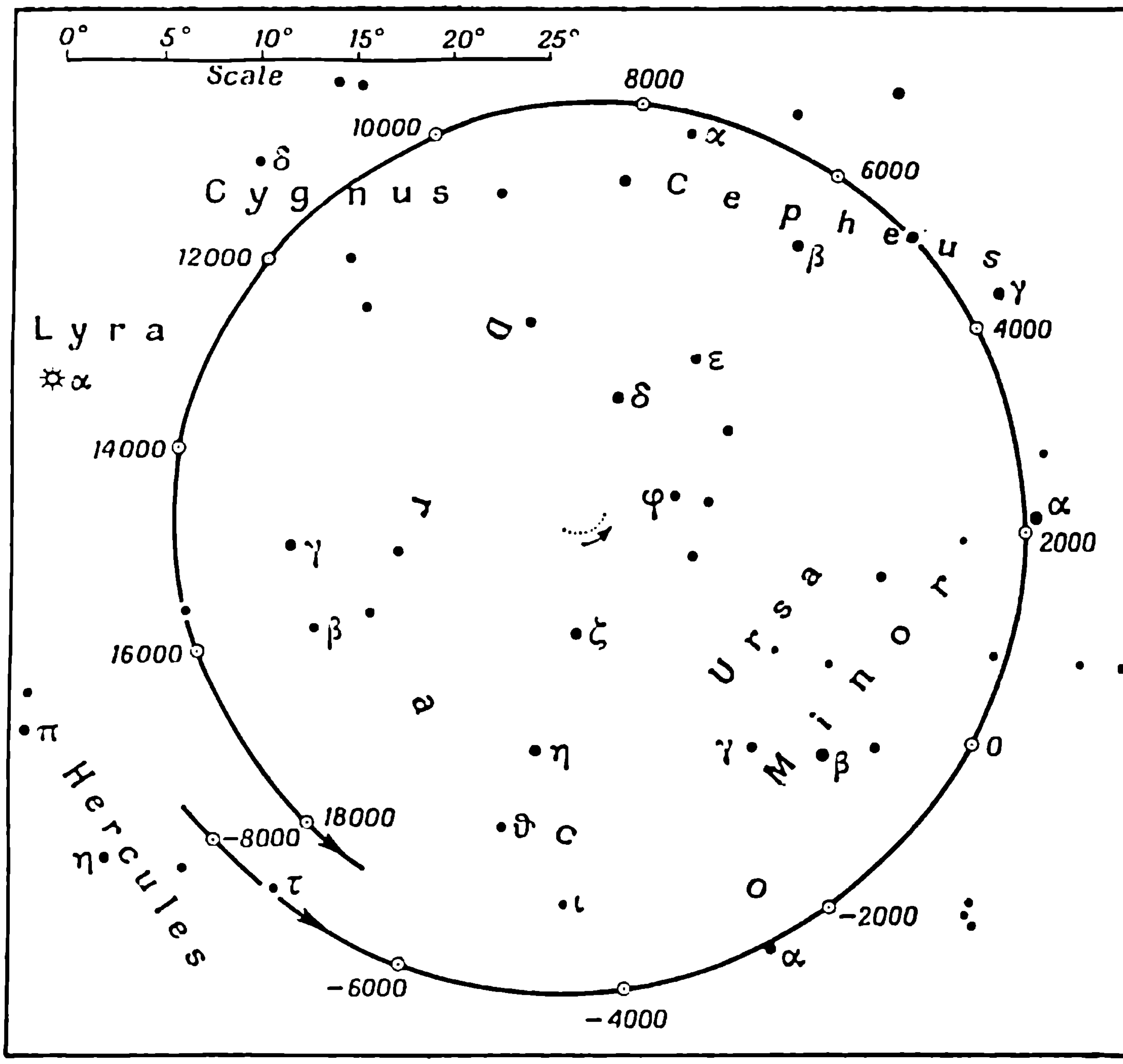


Fig. 22. Precessional translation of the celestial pole among the constellations.

the point of the vernal equinox (the first point of Aries) and hence the equatorial coordinates of all the stars.

The earth's axis turns very slowly, making a complete circuit and returning to its original position in nearly 26,000 years (Fig. 22). But astronomers have to know the precise positions of the stars in the sky and so are compelled to make allowance for precession.

Star maps and atlases have a grid of equatorial coordinates referred to some specific instant of time. For example, the Small Atlas of A. A. Mikhailov (published in 1958) is made up of charts of the "epoch of the equinox of 1950". This expression means that the equatorial coordinates of stars on the maps of the atlas refer to the equinoctial day of 1950. To compute the coordinates of the stars for any other instant of time, the star atlases give special "Precession Tables". Knowing the place of a star in the sky for the epoch of the atlas, it is possible to compute (with the aid of the

precession tables) corrections to the coordinates (with respect to α and δ) for any interval of time.

For general surveys of the sky a star globe is useful; a globe is also used when solving simple problems in spherical astronomy. But even the best globes can never take the place of a star chart, one reason being that on the globe all constellations are turned inside out: the observer is assumed to be located at the centre of the globe.

A few words are in order about the designations of objects on a star map. The present system of designations developed gradually under a variety of circumstances and one will encounter symbols from different periods.

The brightest stars in a constellation are denoted by Greek letters, the sequence of the alphabet corresponding to gradually diminishing brightness of the stars in the constellation. True, there are quite a few exceptions to this rule. For example, in the constellation Gemini, the brightest star is Pollux, which has the designation β, while the second brightest star (Castor) is denoted by α.

A small number of stars—usually the brightest ones—have proper names in addition to the literal designation. For example, Alpha (α) Canis Majoris is known by the name Sirius, Beta (β) Geminorum is called Pollux. At times even faint stars have retained their ancient names. Such is Alcyone, the principal star in the Pleiades cluster. It is otherwise known as η Tauri.

Capital letters (Latin alphabet) have been introduced for a number of stars, mainly variable stars: R, N, S, etc., and even double capitals, RR, AE, TT, and so forth.

Generally speaking, star designations are extremely diversified. We shall have occasion to mention such stars as Wolf 359, Lalande 21185, and the like. In astronomical parlance, these names denote stars recorded in the catalogue of the astronomer Wolf under the number 359 or the catalogue of the astronomer Lalande under the number 21185. Certain unique objects are registered in the official catalogues as the "Kapteyn Star" or the "flying star of Barnard" (Barnard's Star).

The "celestial inventory" is far from perfect, and the situation will appear to be worse confounded if we recall that one and the same star is sometimes designated in several different ways. Somewhat simpler are the designations of the star clusters and nebulae. A possible reason

is that the first and, so to say, official and sufficiently complete catalogue of these objects was compiled only in the eighteenth century, whereas star catalogues have existed since remote antiquity.

The first catalogue of star clusters and nebulae was published by the French astronomer Messier in 1781. It included a total of 103 of the brightest objects. Messier did not introduce differentiated designations for such extremely disparate structures as gaseous and dust nebulae, star clusters and galaxies. For him they were only obstacles that hampered his basic work—the search for comets. That is why he compiled his catalogue of "obstacles": so as not to confuse the nebulous patches of luminosity with a new comet. In this way he did a good service to stellar astronomy.

The designations of the Messier catalogue are still retained. For example, the closest large galaxy in the constellation Andromeda has the conventional symbol "M31" (read "Messier 31"). Which means that it occupied the thirty-first place in Messier's catalogue.

In 1888, Henry Draper, using the old catalogues of William and John Herschel, compiled a "New General Catalogue" (NGC) with a total of 7,480 objects. Somewhat later two supplementary volumes (called IC, or Index Catalogue) were added. And so modern star maps and catalogues indicate galaxies with one of three conventional symbols (M, NGC or IC) with the number in the appropriate list.

When an object has been chosen on a star map and it has been figured out where it is located in the sky at a given time, it is still not so easy to find. One difficulty to the novice is the difference in scales of the actual and depicted sky, the black sky background as contrasted with the white background of the map, and many other things. As in everything else, practice is needed.

The best advice to the beginner is: always proceed gradually from familiar stars and constellations to new and unknown objects. Axiomatic though this principle is, it is frequently ignored.

To get a better general picture of the night sky and the configurations and arrangement of the constellations, we advise the reader to keep a star map in front of him (Appendices VI-X). On these maps, binary double and multiple stars are indicated by lined circles, physical variables are indicated by circled dots.

THE CIRCUMPOLAR CONSTELLATIONS

Polaris, which "heads" the constellation Ursa Minor, and the immediately surrounding constellations occupy a portion of the night sky that is termed the *circumpolar* region (see Appendix VI). For the middle belt of the Soviet Union this region of the sky is always open to observation and it is therefore natural to begin our stellar excursion here. Also, among the circumpolar constellations is the famous Ursa Major (The Great Bear) whose seven-star dipper is familiar to everyone from early childhood.

Besides Ursa Minor and Ursa Major, the circumpolar constellations include the constellations Cassiopeia, Cepheus, Draco, Camelopardus (The Giraffe) and Lynx. Now how do we go about locating them in the heavens?

It is best to begin with the constellation Ursa Major. On autumn and winter evenings its dipper, made up of seven stars, is clearly visible in the northern part of the sky. In spring and summer the dipper is much higher in the night sky, and then it has to be sought in the vicinity of the zenith.

In each constellation it is important to locate the principal star, the characteristic portion of the constellation, and only then the other parts and details. The "skeleton" of The Great Bear is the familiar dipper.

From the dipper of Ursa Major it is easy to find the Pole Star (Polaris): take the two extreme stars of the dipper and mentally draw a slightly bent line (in the direction of the convexity of the dipper handle). At a distance of about five times the separation of the stars Alpha and Beta Ursae Majoris, it will pass through a second-magnitude star, which is Polaris. Moving from Polaris towards Ursa Major up we find the smaller dipper with a bent handle: this is the principal part of the constellation Ursa Minor.

Now it won't be difficult to find the constellation Cassiopeia, which lies on the other side of Ursa Major from the Pole Star. Its principal part forms a figure that resembles the letter M with stretched "feet". In certain positions, this celestial letter will be seen upside down, becoming a W.

Between Cassiopeia and Ursa Minor lies the constellation of Cepheus. It is not so noticeable as the other constellations we have just named, and its principal stars do not form a conspicuous configuration. So to locate this constellation (like others of its kind, incidentally) first pinpoint the stars that interest you by proceeding from familiar stars of other constellations. In doing so, make it a rule to consult your star chart as a check. For example, to find Alpha Cephei, note that it is located on the extension of the straight line connecting Alpha and Beta Cassiopeiae at a distance four times the separation of these stars. Having found Alpha Cephei, it will be easy to find the adjacent stars of this constellation and then the more distant ones.

Between the constellations Ursa Major and Ursa Minor is a long straggling constellation Draco. Its characteristic chain of stars is connected by a broken line that culminates in an irregular quadrilateral made up of stars which form the head of a monster.

The constellations Camelopardus and Lynx are some of the most inconspicuous in the whole sky. Only faint stars are seen here and they are hard to find between Ursa Major and Cassiopeia. There are no recognizable shapes here at all, with the result that this is one of the darkest and poorest regions of the sky.

The ancient Greeks related amusing legends about the Bears, Ursa Major and Ursa Minor. According to one, in the olden days when King Licaon ruled Arcadia, one of the King's daughters, Callisto, whose beauty was so remarkable that she took the risk of competing with the goddess Hera, the wife of Zeus, chief of the Olympian gods. The jealous Hera finally took revenge on Callisto: taking advantage of her supernatural powers, she turned Callisto into an ugly she-bear. When Callisto's son, young Arcas, was returning home from hunting and saw the bear at the door of his house, he wanted to kill it, never suspecting that it was his mother. But Zeus, who for quite some time had been much attracted to Callisto, prevented the crime. At the crucial instant he held the hand of Arcas, and took Callisto to the

sky and turned her into a beautiful constellation. Callisto's favourite dog was also made into a constellation, The Lesser Bear, Ursa Minor. Arcas did not remain on the earth for long either. Zeus, in his craze for building constellations, turned him into the constellation Boötes, The Shepherd, fated for eternal time to keep watch over his mother in the heavens. That is why the principal star of the constellation Boötes is called Arcturus, which in Greek means "watcher of the bear".

Still more romantic is one of the stories behind the constellations of Cepheus and Cassiopeia. If we are to believe the tales of the ancient Greeks, Ethiopia was under the rule of the legendary King Cepheus. Once his wife, Queen Cassiopeia, was so imprudent as to boast of her beauty to the Nereids, the sea nymphs. With understandable female jealousy, they complained to the god of the sea Poseidon, who let loose a sea monster to ravage the coasts of Ethiopia. Great was the destruction that this monster wrought as he devastated this prosperous country. Then Cepheus, to pacify Poseidon, offered as a sacrifice to the monster his only and beloved daughter Andromeda.

This beautiful dark girl was chained to a rock on the coast and in tears awaited her tragic fate. At that time, one of the most popular legendary heroes, Perseus, was performing a most extraordinary deed on the other side of the world. He made his way to an isolated island where dwelled the monstrous snaky-haired Gorgon sisters. The glance of a Gorgon was so terrible that it instantly turned the beholder to stone.

But nothing could stop the fearless Perseus. He waited until they had gone to sleep, and then severed the head of one of them—Medusa. At that very instant, from the decapitated body of Medusa there burst forth a winged horse, Pegasus. Perseus straightway jumped on Pegasus and raced homewards.

In his flight over Ethiopia he noticed Andromeda tied to the rock. At that very moment a monster came forth from the depths of the sea and hurled itself at Andromeda. Bold Perseus flung himself against the monster and a long struggle ensued. Perseus emerged victorious for the sole reason that he directed at the monster the deathly glance of the severed head of Medusa. The monster turned to stone and became an island, while Perseus unchained Andromeda

and returned her to her father. This long story ends with the jubilant wedding of Perseus and Andromeda, and the fertile imagination of the ancient Greeks immortalized all these characters in the fanciful figures of the constellations.

The constellation Draco is also bound up with ancient mythology. As the Greek tale has it, this constellation depicts a mythical dragon that guarded a fantastic garden of golden apples. Another myth portrays the celestial dragon as a monster that nearly swallows Andromeda.

All these ancient myths, so marvellous, naive and charming, come to life again and again in numerous magnificent works of art. But the constellations undoubtedly remain the greatest monuments of all to the poetic myth-creators of the childhood of civilization.

Quite different is the origin of the constellations Camelopardus and Lynx. Camelopardus was first depicted on a star map by Barchius, nephew of the great Kepler. The map was published in 1624 and although Barchius does not say how the constellation Camelopardus originated, we may conjecture that it appeared during the great geographic discoveries as a peculiar monument to those who journeyed to the exotic lands of Africa.

The origin of the constellation Lynx is really funny. It was introduced in 1660 by the famous Danzig astronomer Hevelius. His reasoning was simple: "In this part of the sky we find only small stars, and one needs the eyes of a lynx to see and distinguish them." That, then, is the reason why the constellation Lynx made its appearance. Incidentally, Hevelius did not overrate his ingenuity and wrote that "whoever is not satisfied with my choice can draw something else more dear to him, but one thing is clear, and that is that there is too much empty space here to allow it to remain unfilled".

After this general survey of the circumpolar constellations, let us go into a more detailed study of each one separately.

URSA MAJOR, The Great Bear

On modern star maps the constellation Ursa Major occupies much more space than the seven stars that make up the dipper and which are ordinarily associated with this name.

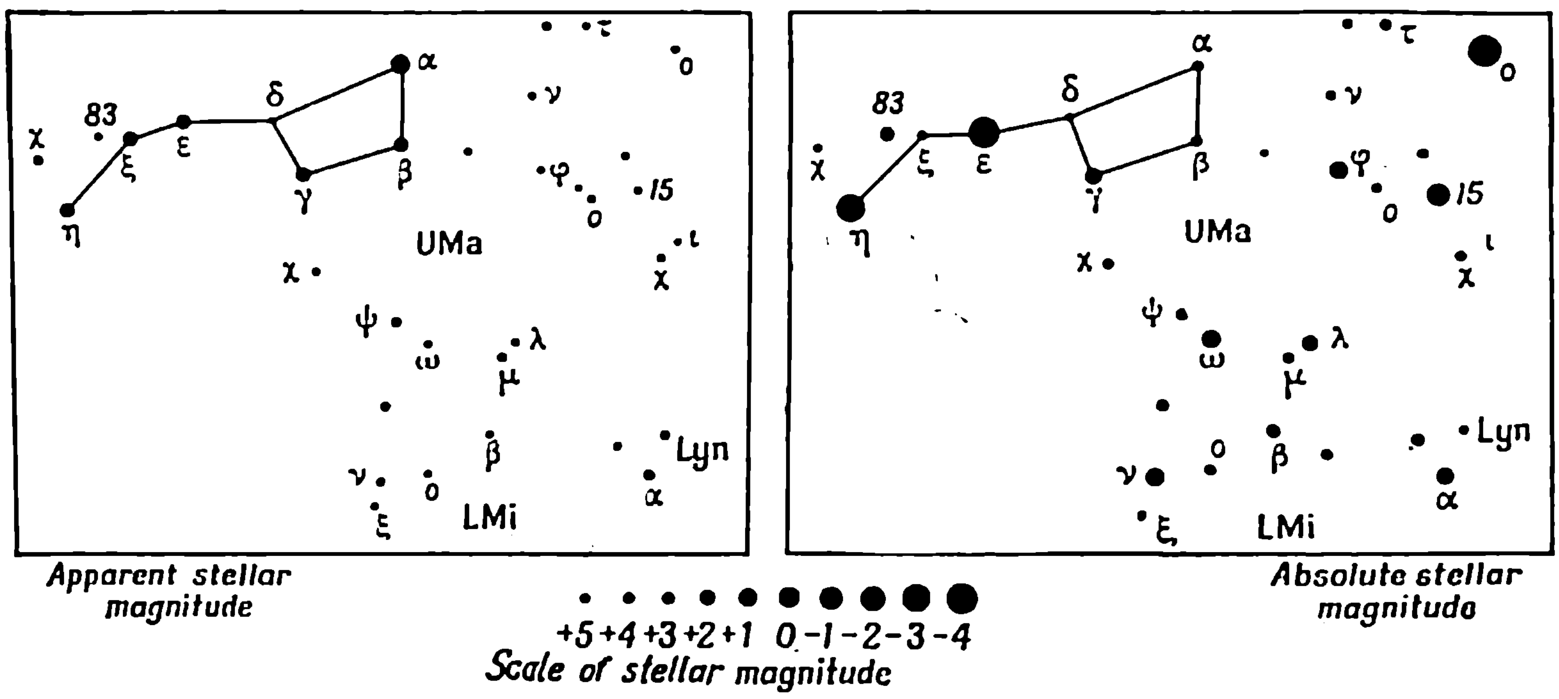


Fig. 23. Apparent and absolute stellar magnitudes of stars of Ursa Major.

To the naked eye, Ursa Major reveals 125 stars, among which our own sun would be a very common star indeed.

To see the figure of a bear in this field of stars, and with a long twisting tail too (something that no earth-dwelling bear has, by the way) one needs a very rich imagination. But the seven principal and brightest stars of the constellation form a dipper which is so clear-cut and conspicuous against the dark background of the night sky that this celestial dipper is the most common starting point for any study of the constellations.

We have already mentioned that the sequence of letters in the Greek alphabet does not always correspond, in all constellations, to the diminishing brightness of the stars.

An instance is the dipper of Ursa Major. One is immediately struck by the star Delta (δ) Ursae Majoris, the one that starts the handle of the dipper, the faintest one in the asterism of seven. And the brightest star in the dipper (on the basis of modern measurements) is Epsilon, not Alpha.

The apparent brightness of the dipper stars is close to second magnitude, with the exception of Delta, which is of Mag. 3.3.

In Ursa Major (Fig. 23) the stars of the dipper are the brightest, but not the closest to us. The nearest of the suns of Ursa Major is a modest little star of Mag. 7.5, which is not visible to the naked eye. It may be found in a prism binocular at the outskirts of the constellation near the bright star Theta (Θ) Ursae Majoris. It takes light eight and a quar-

ter years to cover the distance from this star to the earth. It will be recalled that for Alpha Centauri—the nearest star—light takes only about one half this time. Our modest neighbour in the constellation Ursa Major has not been given a proper name by astronomers, nor does it have a Greek letter. In the star catalogue of the famous astronomer of the eighteenth century Lalande, it goes by the number 21185.

"Lalande 21185" is the designation of this dwarf sun that emits 200 times less light than our sun.

The stars of the dipper have both literal designations and names, which were given them by medieval Arab astronomers, Dubhe (α), Merak (β), Phecda (or Phacd) (γ), Megrez (δ), Alioth (ε), Mizar (ζ), Benetnasch (η). Truly strange names to the modern ear.

To the terrestrial observer, the stars of the dipper appear to be equally distant from the earth (just like all the other stars of the sky, incidentally). Actually, however, the nearest of them is Benetnasch, which is four times as close as the most distant Alioth.

If despite its great distance, Alioth appears as the brightest star in the dipper (when compared for identical distances), it indeed deserves the name of principal star. This naturally applies only to the dipper asterism of seven stars, but not to the whole constellation.

Let us try a mental experiment. We shall put all the stars of Ursa Major at the same distances from the earth and preserve their configuration unchanged. Do you think the constellation will remain the same? Not in the least, it will not even be recognizable.

The little yellow star o that is hardly visible at present will become the principal and brightest star of the constellation. A number of other, very inconspicuous stars will come to the fore. In the dipper, only Benetnasch and Alioth will stand out, the other stars will be lost in the general star background.

The dipper of Ursa Major and, for that matter, all the characteristic figures of the constellations were created by chance—an accidental combination of distances and luminosities of the component stars.

But let us return to the dipper stars. With the exception of Dubhe, these are hot white giant stars with surface temperatures of about 10,000°; Benetnasch even has a temperature in the vicinity of 18,000°. Dubhe is an orange giant

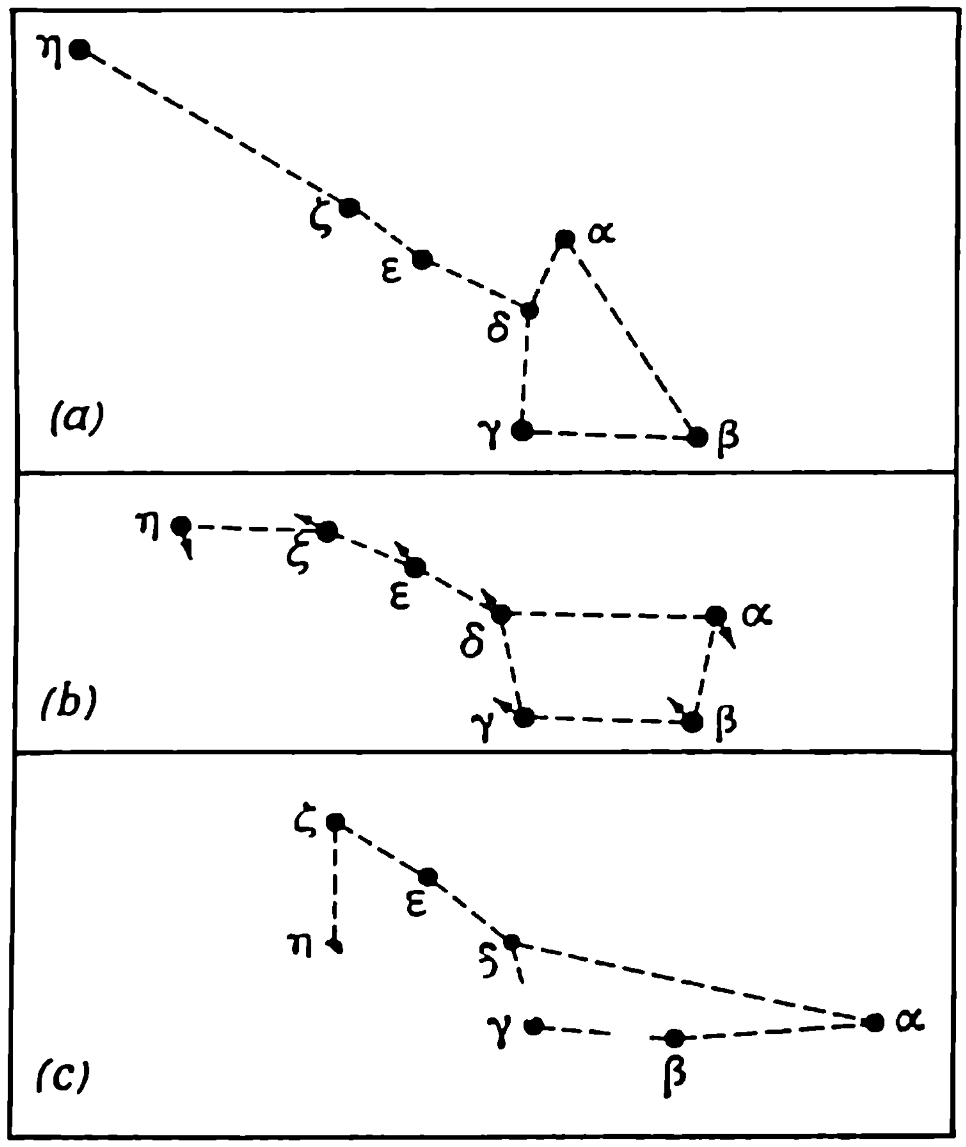


Fig. 24. Motions of dipper stars of Ursa Major.

somewhat cooler than our sun with a surface temperature close to 5,000°.

The stars of the dipper, like all stars, are in motion in space. Here again we fail to see any unifying pattern that would appear to stem from the outward likeness of the dipper stars. Projected on the imaginary celestial sphere, the extreme stars (Benetnasch and Dubhe) are racing off in one direction, while the other stars are hurtling in the opposite direction. As a consequence, the shape of the dipper is constantly changing, though very slowly. Its deformation over hundreds of thousands of years is shown in Fig. 24.

Of the seven stars of the dipper, five are physically similar and are moving in roughly the same direction and with nearly the same velocity. This gives us the right to consider them as a *stellar stream*, a formation of stars of apparently common origin, and not just fortuitous companions in space.

Almost midway between the fore and rear paws of The Great Bear is a tiny star of Mag. 6.5. Only extremely keen-

sighted people can see it with the naked eye; it is seen very well in binoculars.

This star was named after the astronomer Groombridge, who noticed its marvellous features. In the star catalogue compiled by Groombridge in 1810, this unique star goes by the number 1830. What makes it so remarkable?

Outwardly, there doesn't seem to be anything particular. A small yellow star that emits roughly 1/7 the light of the sun. It is even more of a yellow dwarf than our sun. The unusual thing about this star is its extremely rapid motion in space.

In one hundred years it covers an angular distance on the sphere just a bit over a third of the lunar disc. If the stars of the dipper of Ursa Major were dispersing at that rate, stellar motion would have been detected many centuries ago.

In the spectrum of the Groombridge star, the lines are displaced towards the violet end. Which means that it is approaching us (judging from the amount of displacement, or shift) with a velocity of 98 km/s. The total velocity of this star in space is close to 300 km/s.

So fast is the Groombridge star moving, that it will relatively soon leave the constellation Ursa Major altogether and in 6,000 years will be located in the constellation Coma Berenices; 12,000 years hence it will be in the constellation Leo!

The erroneous views of the ancients about the immutability of the heavens were due largely to the fact that not a single bright star visible to the naked eye has such a fast rate of motion.

On a dark starry night take a careful look at Mizar, the middle star in the handle of the dipper of Ursa Major. Alongside it you will easily see a tiny faintly shining star of the fifth magnitude. Medieval astronomers gave it the name Alcor. In Arabic these two names mean "steed" and "rider".

Mizar and Alcor together form the most famous and readily observable double star.

The angular distance between Mizar and Alcor is close to 12 minutes of arc, which is slightly more than a third of the apparent lunar disc. However, the apparent proximity of these two stars is due only to their unimaginable distances from our earth. Actually, the two stars are separated by a

distance at least 17,000 times that of the earth from the sun—close to 2.5×10^{12} km!

This is a truly fantastic number by terrestrial standards, but everything is relative. On the cosmic scale (interstellar distances) Alcor is really quite close to Mizar: in fact, 16 times closer than the sun is to Alpha Centauri. It might even be that Mizar and Alcor make up a physically interrelated system of two stars revolving about a common centre of gravity, though no such motion has yet been detected. Incidentally, it is difficult to see how we can expect an early success, especially when we recall that the orbital period of Alcor round Mizar should be in the neighbourhood of two million years. There is nothing surprising, therefore, in the fact that during hundreds of years of constant observations astronomers have not detected the slightest shift of Alcor in its orbit.

The unaided eye sees Mizar as a single star, but even the smallest telescope readily resolves it into two components. This discovery was made by the astronomer Riccioli, a contemporary of Galileo. Both stars—Mizar A and Mizar B—are hot white giants. Both revolve about a common centre of gravity with a period of the order of twenty thousand years.

That is not all. Spectral analysis has established that Mizar A in turn consists of two stars that are almost in contact whirling about in a cosmic waltz—how else can we describe this system with its orbital period of only $20^1/_2$ days!

No telescope can resolve the double nature of this star. Only minute spectral effects assure us that the star is indeed double, a true binary. A truly remarkable system of four suns engaged in an intricate cosmic dance.

The constellation Ursa Major has quite a collection of double stars. But particularly outstanding is the relatively bright star (fourth magnitude) designated by the letter ξ. It can be found under the rear paws of The Great Bear, not far from the constellation Leo Minor.

Two yellow stars, almost the same, and very much like our sun, revolve about a common centre of gravity with a period of 60 years. Xi Ursae Majoris is the first binary for which an orbit (one star relative to the other) was computed (in 1830) and for which the period of revolution was reliably determined. It was thus demonstrated for the first time that

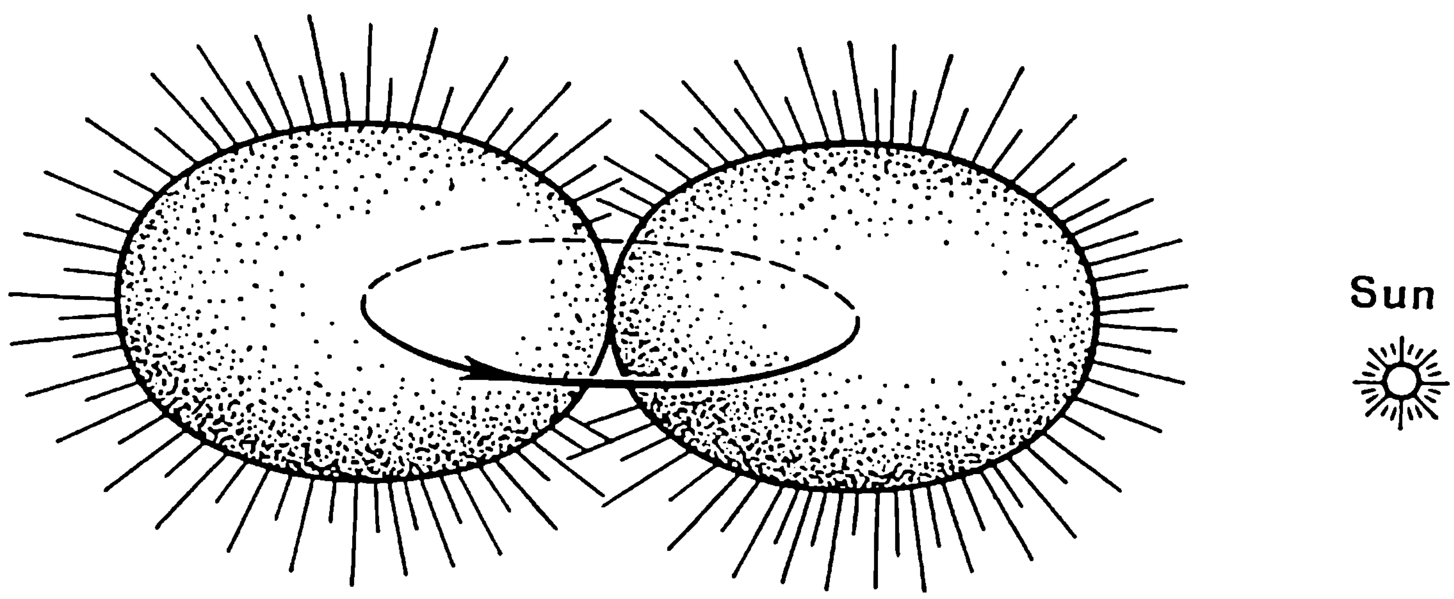


Fig. 25. W Ursae Majoris type star.

the law of universal gravitation manifests itself in the world of stars. Much later it was discovered (again by means of spectral analysis) that the stars ξA and ξB are in turn accompanied by companion stars, for one of which the period is 669 days and for the other only 4 days.

Again we have a system of four suns and this time most certainly related physically!

Careful observations indicate that many of the stars of Ursa Major (mainly those that are visible only in a telescope) vary in brightness, in apparent brilliance.

Of all the variable stars of Ursa Major, let us examine one that belongs to the so-called class of eclipsing variables. The star W Ursae Majoris, which we shall discuss, is by no means ordinary. It is unique, and not only in the constellation Ursa Major, but in the stellar sky at large.

The two stars that make up this system are so close that their mutual attraction has altered their shapes, changing them from spherical bodies into elongated, egg-like ellipsoids (Fig. 25). These two bodies revolve about their common centre of gravity with the bulges always pointing to each other. It only takes about eight hours for them to return to their original positions; that is how brief their period of variation of brightness is, unparalleled by any other variable star.

It will readily be seen that as these stars that make up W Ursae Majoris circle about, the terrestrial observer sees first a narrow part, then a broader body. The amount of light that the stars send to the earth also varies accordingly. There is no existing telescope that can resolve them. All the

information we have about W Ursae Majoris has been culled from a careful analysis of the curve of variation of apparent brightness (light curve), which ranges between Mags. 7.8 and 8.6.

Now try to imagine how unusual our sky would be if the sun were like this remarkable star of the Ursa Major constellation. In place of a steady bright sun we would have two egg-like bodies almost in contact circling round one another.

The constellation Ursa Major has six bright nebulae that appear in the Messier catalogue under the numbers 81, 82, 97, 101, 108, and 109. Five of them are very much alike and form distant stellar systems: galaxies. The sixth nebula, symbolized by M97 (read: "Messier 97") is radically different from the others.

First of all, it is not a stellar system, but an enormous spherical cloud of luminous gas. Outwardly, it resembles a planetary disc, whence the name for such structures: planetary nebulae. Powerful telescopes reveal the planetary nebula of the Ursa Major constellation to be like the face of an owl. That is why astronomers call it (unofficially) "The Owl".

In the centre of the nebula, as usual, is a very hot white star. There is reason to think that the gases which form the nebula were once ejected by the central star in some kind of explosive process that is not yet thoroughly understood. At any rate, the nebula is at present expanding in all directions from the star, which is an obvious indication of the source.

The Owl Nebula is a very distant object and difficult to observe. It is 2,290 parsecs from the earth and has an apparent magnitude of about 12. Knowing the visible angular diameter of the nebula, it is easy to compute that it is nearly 230,000 times the diameter of the earth's orbit. Nevertheless, this is an object within our stellar system, the Galaxy. It was only the imperfect telescope of Messier that made the astronomer confuse gaseous nebulae with other stellar systems and list them in his catalogue.

Among the rich treasures of Ursa Major hidden from the naked eye are a multitude of galaxies. We mention only three stellar systems: M101, M81, and M82.

The M101 galaxy may be detected in a small telescope in the form of a tiny patch of luminosity of stellar Mag. 8.2 not far from Mizar, above the tail of The Great Bear (see

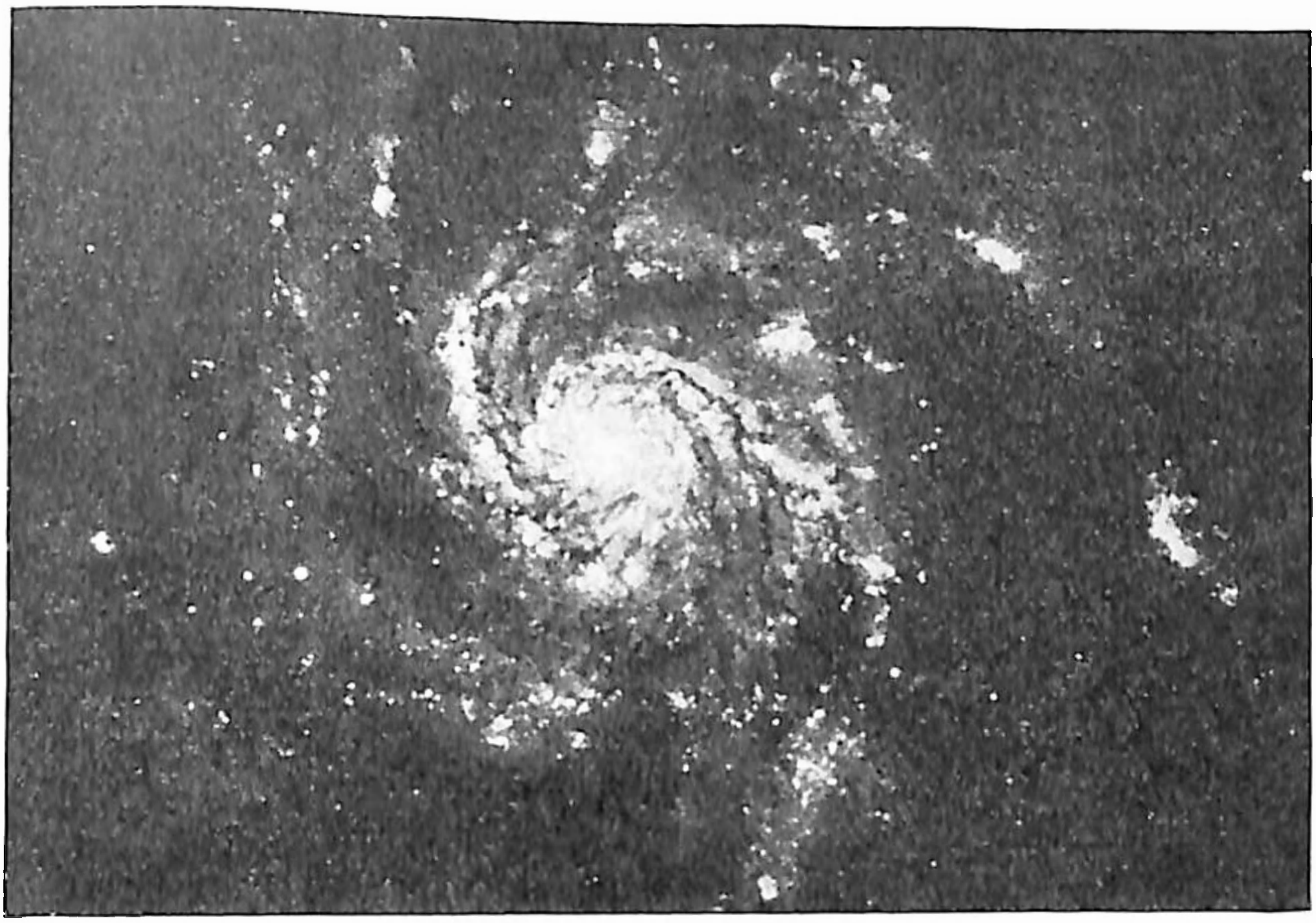


Fig. 26. The M101 galaxy.

the photograph in Fig. 26). It is a magnificent stellar spiral, which, thanks to a trick of fate, we see flat-on. This great stellar system is composed of thousands of millions of suns. Thousands, perhaps millions, of planets in this galaxy are inhabited by creatures that, we conjecture, have listed our own Galaxy in their catalogues, for our star system should be quite a sight from the M101 nebula. If we imagine them to have telescopes (perhaps supertelescopes) that would enable them to see our earth, they would not see any human beings because in their field of view the earth would be seen as it was about eight million years ago—that is how much time it takes light to cover the stupendous distance between M101 and our Galaxy!

The two other galaxies—M81 and M82 of Mag. 7.9 and 9.2—form a double galaxy, a sort of analogue of a double star. They are seen close together among the stars where the ancient Greeks perceived the snout of The Great Bear. This pair of star systems is at a distance of about 2,300 kiloparsecs. The M81 galaxy (like M101) is a reduced version of our own stellar system. It has a diameter about one fourth of

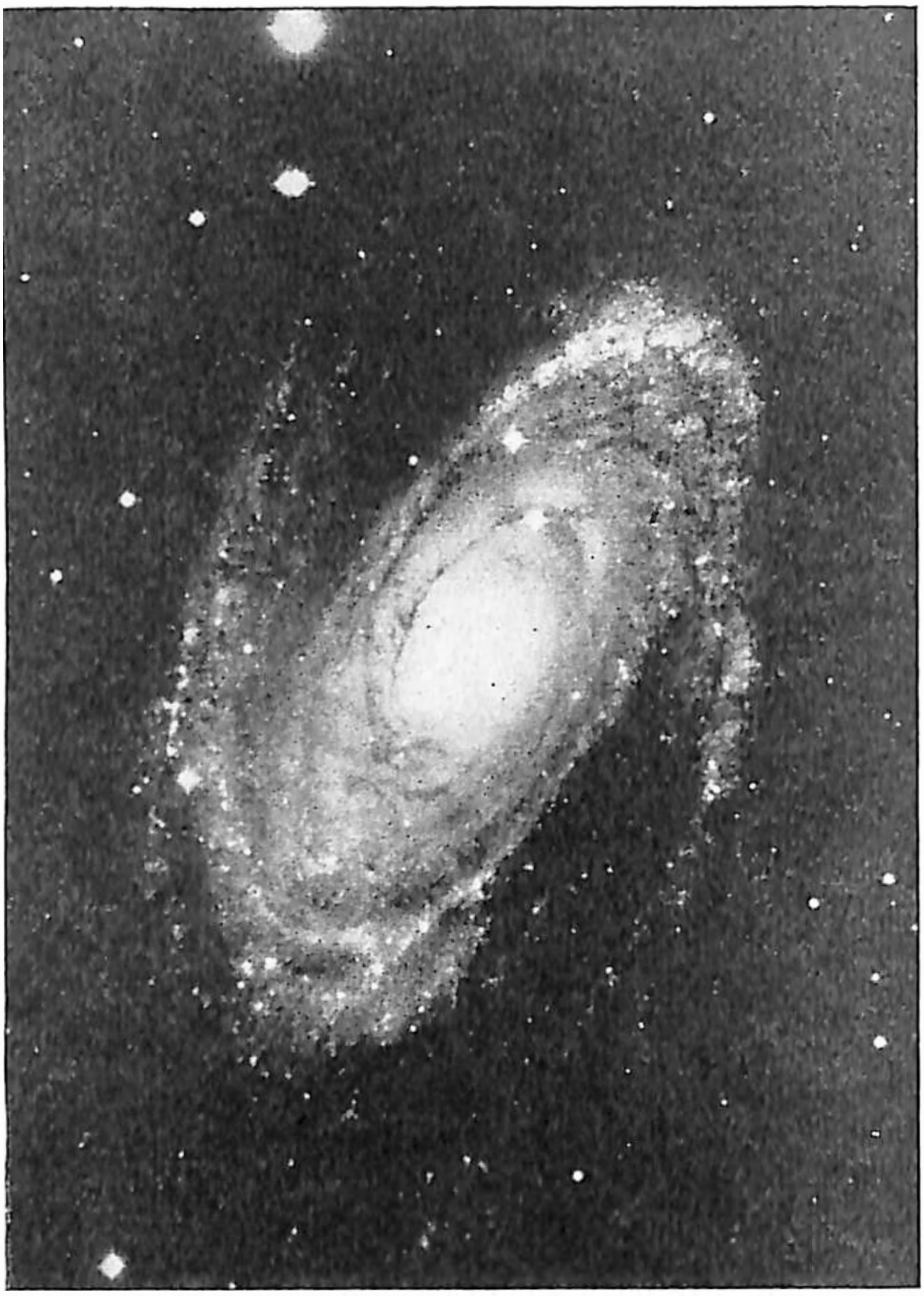


Fig. 27. The M81 galaxy.

ours, and it is turned a bit sideways towards us. But its spiral structure stands out clearly (Fig. 27).

The M82 galaxy is quite different. We see it edge-on and in the form of a patchy nebulous cloud. An irregular type galaxy, that is what astronomers call such stellar systems.

The distribution of matter in the observable portion of the infinite universe has one peculiarity: extreme nonuniformity. Stars form double, triple and other multiple systems. There is an uninterrupted sequence from them to star clusters and galaxies. And even the stellar systems them-

selves often unite into pairs, groups, and even stupendous clouds of galaxies that defy the imagination.

In Ursa Major we find three such clouds or clusters of galaxies. The biggest family here contains three hundred galaxies. The central portion of this cluster alone has a diameter of 200 kiloparsecs. However in the sky this cloud occupies an area just a little bigger than the moon's disc.

As a whole (disregarding the secondary motions of one galaxy relative to another), this cluster of galaxies is receding from the earth at a velocity of 15,000 km/s! Which is not a misprint. The speed is 10,000 times that of a bullet; that is how fast this cloud of galaxies is racing away.

It has been established that all galaxies are receding from the earth, but don't think that it is because this is the worst place in the universe. Simply, the entire system of known galaxies is in a state of expansion. That, incidentally, is what causes the famous "red shift".

Thousands of millions of years ago, a fantastically powerful explosion of some kind is thought by some to have given birth to this outrushing of galaxies. It would be meaningless, of course, to generalize and extend this conclusion to the entire infinite universe. But there can be no doubt about the fact that our portion of the cosmos is expanding.

The magnificent panorama unfolding in the constellation Ursa Major suggests possible pathways in the evolution of stellar worlds and the generation of galaxies. Take that familiar couple: M81 and M82. Judging from their spectra, one of them is racing away from us with a velocity of 187 km/s, the other at 74 km/s. Now this means that one of them is receding from the other at a velocity of at least 113 km/s. Whence it is natural to conclude that these galaxies were born together and at birth received some kind of initial velocities that cause the system to expand continuously.

There are a great many such instances which cogently prove that all galaxies (like stars) are produced in groups out of some kind of pre-stellar matter of a still unknown nature.

URSA MINOR, The Lesser Bear

The principal star of this constellation is Polaris, the Pole Star, which is the chief spectacle of the asterism.

Polaris is known not so much for its physical pecu-

liarities (few know about them), as for its proximity to the north celestial pole. Of the bright naked-eye stars, there is no other that can compete with Polaris in this respect, though with binoculars it is easy to locate a star of Mag. 6.4 (conventional symbol: 2*r*) that is closer to the celestial pole than Polaris.

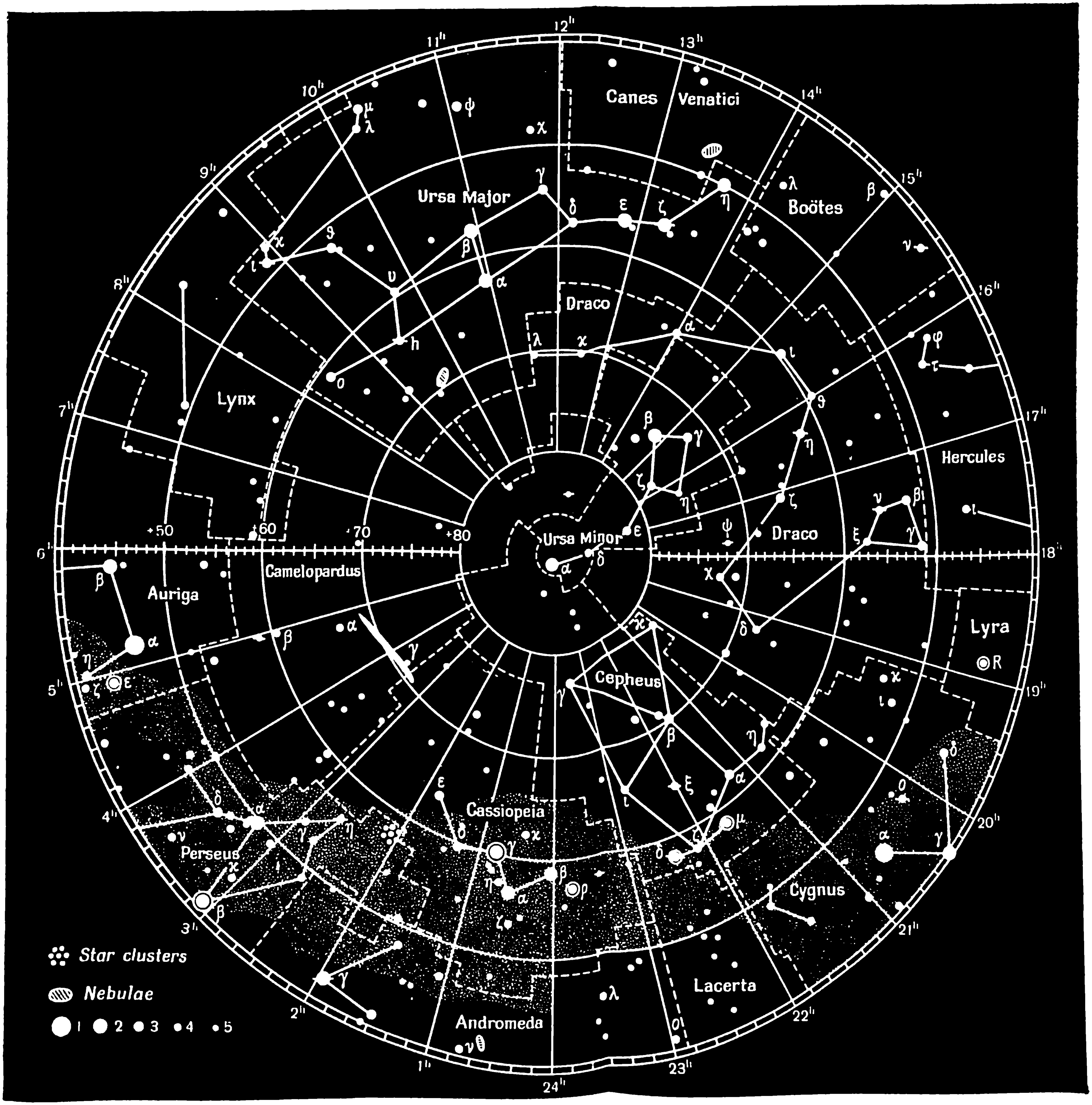
The unique role of Polaris is temporary. We have had occasion to note that the precessional motion of the earth's axis produces a constant (though very slow) wandering of the celestial pole among the constellations. Some three thousand years ago, the star closest to the pole was Beta Ursae Minoris. In brightness it is inferior to Polaris by only a tenth of a magnitude. It even has a proper name, Kochab, which comes from the Arabic "Kochab-el-Shemali", or "star of the north". In China Beta Ursae Minoris is known as the "royal star", which most likely echoes the leading-star role of remote times, the part that is now played by the Pole Star, Polaris.

Binoculars clearly show the yellowish hue of Polaris. It is somewhat hotter than the sun with a surface temperature close to 7,000°. Polaris belongs to the supergiant star type. Alongside this massive star, our sun would look modest indeed; in diameter Polaris is 120 times greater than the sun.

Another remarkable thing is that Polaris is a pulsating star that increases in volume and then diminishes again. In the process, there are variations of temperature and brightness as well as changes in the spectrum of the star. At maximum, Polaris is a star of Mag. 1.96, at minimum, 2.05. The strange stellar mechanism functions with a very strict rhythm, the period between adjacent maxima coming out to four earth days.

Polaris lies at a distance such that a light ray reaching the earth today would have left Polaris 472 years ago. In other words, we see Polaris the way it was in the days of Columbus!

The Pole Star is a typical Cepheid and it's a very good thing that our sun is different, otherwise we would have to go through constant ups and downs of temperature and light. Then again, replacing the sun with Polaris would lead to catastrophic results even if the latter were not a Cepheid, for since it emits streams of light and heat nearly 10,000 times more powerful than our sun does, Polaris would very soon wipe out all organic life on this earth!



Canes Venatici
Ursa Major
Boötes
Draco
Lynx
Hercules
Ursa Minor
Camelopardus
Auriga
Lyra
Cepheus
Perseus
Cassiopeia
Cygnus
Lacerta
Andromeda
Star clusters
Nebulae
1 2 3 4 5
+50 +60 +70 +80

In the large school refractor we can see a tiny ninth-magnitude star right next to Polaris (18 seconds away), the companion star. It was discovered in 1779 by the famous explorer of the night sky William Herschel. It may be that this star is physically related to Polaris, though it is not easy to note any orbital motion directly: the orbital period of this system must be very great.

Polaris and its companion star differ very slightly as to temperature, the companion being somewhat hotter. But in size, these are two totally different objects. Polaris is a supergiant, its companion is a yellow-white star only just slightly larger than our sun.

Incidentally, the companion appears greenish in a telescope. We have already warned the reader that the observer in such cases is the victim of an optical illusion, though a beautiful one. Without it, many double stars would appear rather drab and uninteresting.

That seems to be all the sights of Ursa Minor, this tiny asterism that unites a total of 20 naked-eye stars.

CASSIOPEIA

It was November of 1572 when Tycho Brahe, the famous astronomer, was returning from Germany to his native Denmark and stopped over in the picturesque old monastery of Herrizwald. This is what Tycho Brahe relates: "One evening when, as usual, I was scanning the heavens, which I know so well, near the zenith, to my undescribable astonishment, I saw a bright star of unusual magnitude in the constellation Cassiopeia. Struck by this discovery, I did not know whether to believe my own eyes.

"The new star did not have any tail, it was not surrounded by any nebula, it was in all respects like the other stars of first magnitude.... In brightness it might be compared only with Venus, when the latter is nearest the earth. Those with keen eyes could distinguish this star in broad daylight, even at noon. At night, when the sky was overcast and the other stars hid behind the clouds, this new star was even visible through a rather thick cloud cover.

"Beginning from December of 1572 its brilliance began to diminish.... It passed from the fifth magnitude to sixth between December 1573 and February 1574. The next month the new star, having shone brightly for seventeen months,

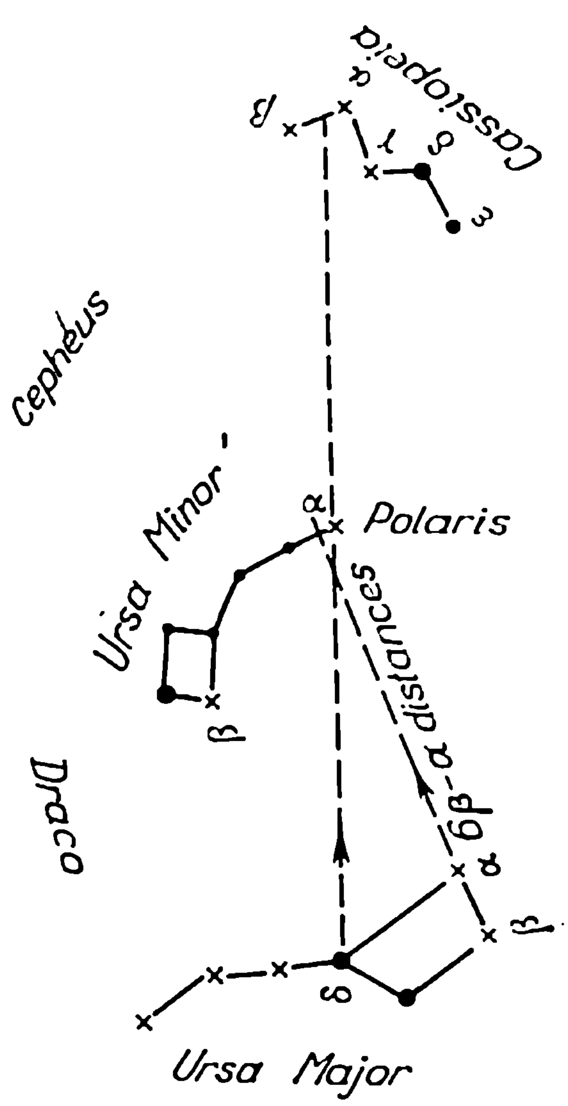


Fig. 28.

vanished without leaving any trace visible to the unaided eye."

If the inquisitive mind of the scholar was struck by this unusual celestial occurrence, you can imagine what confusion it caused in the minds of the simple people of Europe! Still fresh in their memory was the Massacre of St. Bartholomew. It was only a few months before the appearance of this new star that large numbers of Huguenots were massacred by the Catholics. There was talk that the star in Cassiopeia forewarned of the end of the world and the Day of Judgement. Many prepared for death.

Nothing dreadful happened, however. The world remained intact, and superstitious fears vanished with the disappearance of the mysterious luminary. But what actually did take place in the depths of space in that year?

Tycho Brahe very accurately measured the equatorial coordinates of this extraordinary star, and today we can be sure of the very point in Cassiopeia where it burst forth. This point is near the star $\varkappa$, but unfortunately, neither Kappa, nor any one of the many faint stars in this region of the sky can be called "Tycho's star". Their physical characteristics are just too ordinary for this.

In 1952, exactly 380 years after these events, feeble fluxes of cosmic radio waves were found to be emanating from the very spot that once generated the new star. And these hard-to-detect radio signals are the only remnants of that amazing celestial fireworks. At least the only ones that we have been able to pick up.

On modern views, Tycho's star is one of the so-called supernovae. These astronomical objects are perhaps the most remarkable of recent discoveries. Judge for yourself.

Supernovae are exploding stars. Some sort of intricate, as yet unresolved, processes upset the stability of such a star and the accumulated nuclear energy is suddenly released in explosive fashion into surrounding space. The total quantity of energy ejected in the outburst of a supernova is truly fantastic—10^{50} ergs!

When a supernova explodes, it blows up to stupendous dimensions. Then it flings off the outer shells of gas and begins to contract. Judging from a variety of data, after the explosion a supernova becomes a superdwarf star only a few kilometres across. But then the density of the matter is hard to imagine—hundreds of thousands of tons in a pinhead!

But what of the gaseous shells? They leave the mother star and race off in all directions to form a gaseous nebula. In such nebulae—the remnants of explosions of supernovae—there are many fast electrons ("relativistic", they are called), the accelerated motion of which in the magnetic field of the nebula gives rise to radio waves.

Our telescopes are not yet powerful enough to perceive the highly contracted Tycho star or, for that matter, its surrounding radio nebula. Only the radio waves generated by this nebula tell us about the earlier cosmic cataclysm.

Cassiopeia has the most powerful source of radio waves (called Cassiopeia A) anywhere in the sky. The radio flux from this region of the sky is many times more powerful than the radio emission from Tycho's star.

In 1951, photographic plates sensitive to red rays were used in recording bits of a small radio nebula associated with Cassiopeia A. On the other hand, ancient Chinese chronicles noted that precisely at this spot in 369 A.D. a very bright "guest star" made its appearance. Which means that Cassiopeia A, the most powerful cosmic radio station, originated in the outburst of a supernova.

We have mentioned two sights in the constellation Cassiopeia which no optical telescope can show us. Still it is interesting to know the places in the sky where these absolutely unique objects can be found.

The most powerful of all explosions are in supernovae; they apparently result in irreversible changes in the star. In some stars, similar outbursts are known to repeat, and the smaller the energy scale of the outburst, the more frequent the recurrence. These are novae and nova-type stars.

The constellation Cassiopeia has two very peculiar stars, Gamma and Rho, which may be put in the class of nova-type stars.

Astronomers got interested in Gamma Cassiopeiae last century. At first glance there does not seem to be anything striking. But the spectrum of the star exhibits bright emission lines, which is a definite sign of big-scale movements of incandescent gases in the star's atmosphere.

The brilliance of Gamma Cassiopeiae is known to vary irregularly and drastically. For example, in 1937 it became the brightest star of the constellation. It probably experienced something in the nature of an explosion, the atmosphere expanded and part of the gases was thrown out into space. Afterwards, the star calmed down a bit, but sudden flares of brightness have been observed since. There have been periods when Gamma Cassiopeiae became a star of Mag. 1.6, while during periods of low brightness it falls to the third magnitude.

Quite different is the behaviour of Rho Cassiopeiae. Most of the time its brightness remains unchanged at about fourth magnitude. But then a decline sets in and it goes to Mag. 6.2; then the star is no longer visible to the unaided eye. The reasons for these fluctuations of brightness are as yet not known. One thing is certain: both Gamma and Rho Cassiopeiae are restless nonstationary stars with unstable atmospheres. Unravelling the mystery of stellar outbursts, both the grandiose and the relatively small ones, will undoubtedly enrich atomic physics with new facts and fresh conceptions.

Now turn to the binary star Eta Cassiopeiae. The primary star is of Mag. 3.7 and is a yellow giant, its companion star is of Mag. 7.4 and is a small red cool star with a surface temperature in the vicinity of 3,000°. The two stars are separated in the sky by 10 seconds of arc and revolve about

a common centre of gravity with a period of 526 years. They are comparatively close to the earth: we see events in this binary system only twenty years behind the times.

The Cassiopeia constellation has a yellow dwarf of Mag. 5.3—Mu Cassiopeiae. It is remarkable for its great speed. Every second it recedes from us by about 100 km. In one thousand years it covers a distance in the sky equal to double the apparent diameter of the lunar disc. It was first listed in the star catalogue of Tycho Brahe.

On dark nights, between the stars Delta and Epsilon, one can see two small open star clusters, NGC 457 and NGC 581. The former has a visible diameter of 14′ and includes 50 stars. The latter has fewer stars: 30 located in an area 6′ across. Of the open clusters these are some of the most distant. The first is 2,100 parsecs away, the second, 2,500 parsecs. These objects appear tiny to the terrestrial observer but they have diameters of 8.5 and 4.8 parsecs, respectively. In a small telescope they are hardly worth speaking about. All the more interesting is it to compare them with the Pleiades, which are close to us and form the most impressive open star cluster in the sky.

CEPHEUS, The Sea Monster

The tall young man with the fine regular features was deaf and dumb. Every starry night he would observe with close attention one of the stars of the constellation Cepheus, the one listed in the star catalogues under the letter Delta. At times the star would appear brighter than usual, at others, fainter. Could this be an optical illusion? So strange these fluctuations of brightness.

Days and weeks passed and, finally, there could no longer be any doubt. With the regularity of clockwork, Delta Cephei reached a maximum every five and a quarter days and then smoothly diminished to lowest brightness.

The brightness of the star at various instants of time was computed, a light curve was drawn that indicated a periodical twinkling of Delta Cephei. More, a whole new class of variable stars was discovered and named Cepheids in honour of the type object of the class.

The discoverer was John Goodricke, born in Holland, educated in England. A year before the discovery of the first Cepheid in 1782, the Royal Society of London awarded

him the Copley Medal, its highest award, for the discovery of the variability of Algol, one of the principal stars in the constellation Perseus. This talented investigator died very young, in 1786, at the age of 21. But astronomers are lucky in that their names become associated with the longest living of all objects, astronomical bodies.

If you want to see for yourself that Delta Cephei varies, repeat what Goodricke did. No need to fear, this is easy enough. Near Delta Cephei we see the stars Zeta (Mag. 3.6), Epsilon (Mag. 4.2) and Nu (Mag. 4.5). Let us now compare the brightness of the variable star with that of the constant "comparison star". Suppose that at the time of observation, Delta Cephei is definitely fainter than Zeta, but brighter than Epsilon. We mentally divide the interval of brightness between the comparison stars into 10 equal parts and attempt to estimate the position the variable star would occupy in this interval. If, say, Delta Cephei is just as many times fainter than Zeta as it is brighter than Epsilon, then the estimate of brightness may be written like this: $\zeta 5 \delta 5 \varepsilon$. At other times we may obtain different evaluations: $\zeta 3 \delta 7 \varepsilon$ or $\zeta 6 \delta 4 \varepsilon$. Knowing the magnitudes of ζ and ε, it is easy to compute the brightness of the variable by proportional division. Delta Cephei is sometimes fainter than Epsilon, and then for the comparison stars we can take ζ and ν or ε and ν.

In the course of two or three weeks you will have made a dozen or so estimates. Now you can construct a curve of the brightness variation of Delta Cephei: horizontally, lay off the time, vertically, the apparent brightness. The more observations, the more obvious becomes the periodic nature of brightness variation of Delta Cephei.

We repeat that the brightness of Delta Cephei varies with remarkable regularity. Its period has been determined to within 5.366306 days! The character of the variation of brightness hardly at all changes from period to period, and so for Cepheids and other periodically variable stars astronomers construct an overall (or mean) curve, reducing all observations to a single period (Fig. 29).

The rapid rise in brightness to Mag. 3.6 and the relatively slow decline to 4.3 are characteristic both of Delta Cephei and of other stars like it, which are termed *Cepheids*. Observations indicate that other physical features of Delta Cephei vary in step with brightness: colour, temperature, line-

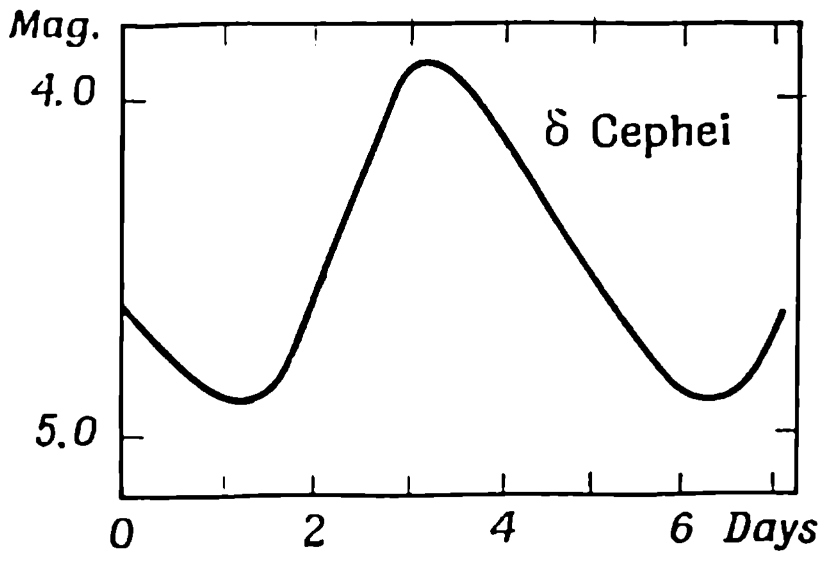


Fig. 29. Light curve of Delta Cephei.

of-sight velocity. The spectral class fluctuates as well: at maximum brightness, Delta Cephei is a star of class F0, at minimum, its spectrum is characteristic of stars in class G0.

It was no easy job to figure out all these intricate phenomena, but now the nature of Cepheid variations has been largely clarified. They are white-yellow giants in which, for some unknown reasons, the inner equilibrium has been upset. Like a pendulum, they are constantly pulsating with consequent changes in brightness and other physical features. The pulsations of the Cepheids, like everything in the world of stars, are on a tremendous scale. Their radii change by millions of kilometres, which however is, on the average, only about 5 per cent of the mean stellar radius.

When a Cepheid is contracted to the limit, the surface temperature is highest and the star reaches peak brightness. Conversely, the largest dimensions correspond to lowest temperature and minimum brightness.

The picture here at home would be terrible indeed if our sun were a Cepheid. But the sun is a yellow dwarf, and Cepheids are white-yellow giants. There is very little in common between them.

This constellation has another bright Cepheid, Beta Cephei, with a very brief period of brightness variation—only 0.19 day—and the amplitude is small as well: Mag. 0.05. To the naked eye it is always of equal brightness, but extremely sensitive astronomical photometers detect even such minute fluctuations of brightness. And they recur just as regularly as those in Delta Cephei. But Beta Cephei is not a typically "classical Cepheid". It belongs to a spe-

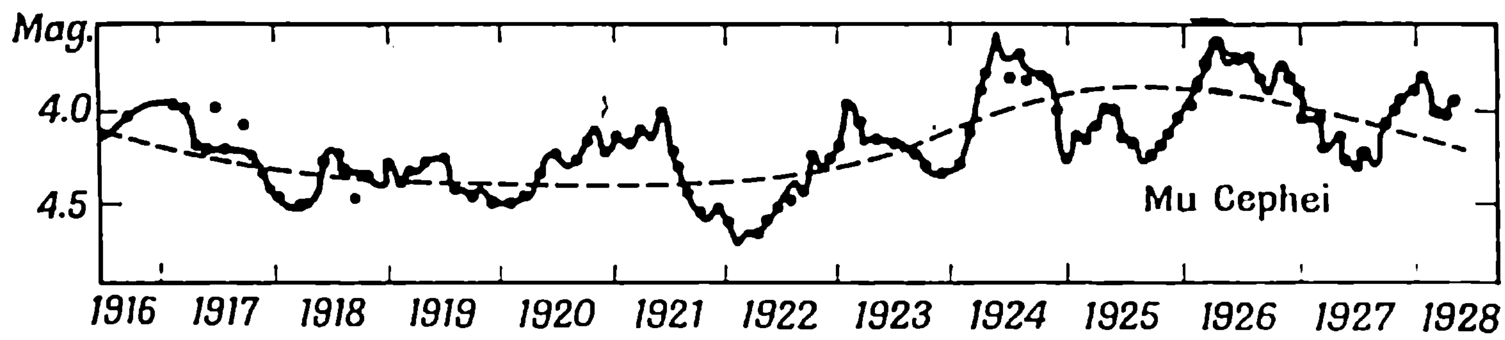


Fig. 30. Light curve of Mu Cephei.

cial class of variable stars of the Beta Canis Majoris type. They are all much hotter than ordinary Cepheids and are hot white giants. Fluctuations of brightness are partly due to pulsations, but there is every reason to believe that they are supplemented by complicated phenomena occurring in the atmospheres of the stars. There is still much to learn here. Meanwhile, stars of the Beta Cephei type are considered to be a variety of the Cepheids.

Midway between Alpha and Delta Cephei, not far from the straight line joining these two stars, is a unique star, Mu Cephei. William Herschel was the first to notice its unusual dark red colour; he called it the "garnet star". The most beautiful of all bright naked-eye stars, this red sun shines radiantly in the depths of space like a translucent droplet of blood. To appreciate the colour of Mu Cephei, take binoculars and first look at the white star Alpha Cephei, then at the red beauty. This is no optical illusion nor is it any kind of complex psychophysiological effect; it is simply one of the coolest of stars with a surface temperature that hardly exceeds 2,000°.

Mu Cephei is quite a distance from the earth, and we see it with a "lag" of about one thousand years. Nevertheless, Mu Cephei is one of the few stars whose diameter was measured directly (by means of an interferometer). It turned out to be one of the largest of all stars with a diameter nearly 1,500 times that of our sun.

It has been noticed that the brightness of Mu Cephei is not constant, but varies rather irregularly with the amplitude sometimes reaching Mag. 0.6. The Soviet variable-star specialist V. Tsesevich was able, with great difficulty, to establish that these apparently random fluctuations of brightness are governed by certain regularities. The complicated light curve of Mu Cephei (Fig. 30) may be regarded as the result of a combination of three fluctuations with pe-

riods of 90, 750 and 4,675 days. This type of star is called a *semiregular variable*; Mu Cephei is a typical representative of one of the subclasses of these stars.

It is still difficult to say definitely what causes the brightness fluctuations of stars like Mu Cephei. There are obviously random (or, better, semiregular) pulsations and some kind of nonperiodic eruptions of incandescent gases from the interior into the atmosphere. At any rate, there are absolutely no reasons for regarding these supergiant red pulsating goliaths as "extinct" stars (as Flammarion of last century thought).

The constellation Cepheus has two remarkable double stars. Not new ones, but the familiar Delta and Beta Cephei.

The most important of these Cepheids has a companion of Mag. 7.5 at an angular distance of 41″. The golden-yellow Cepheid and its bluish companion star form one of the most beautiful close star-pairs in the whole sky.

Still more exciting is the Beta Cephei system. The primary star is a spectral binary with an orbital period equal to the period of brightness variation: 0.19 day. The eighth-magnitude blue companion star is at a distance of 8″ from the primary white star. The companion undoubtedly revolves round the primary (or, to be more exact, both stars revolve about their common centre of gravity) with a period of apparently 50 years. What we have here is a physical system of three stars, and the primary is a variable of a very complex nature that is posing no small number of questions to present-day astronomers.

DRACO, The Dragon

The brightest star of this constellation, Gamma Draconis, is involved in a curious and very instructive story. In 1725, James Bradley, Professor of mathematics and astronomy at Oxford University, decided to prove the truth of Copernicus' hypothesis. Although 182 years had passed since the publication of the book of the great Polish astronomer, his ideas about the motion of the earth round the sun were still only a conjecture of genius without any supporting facts.

If the earth does move round the sun, the close-lying stars should exhibit a shift on the distant-star background, describing in the course of a year tiny ellipses that would

be a kind of reflection of the earth's orbit on the celestial sphere.

The farther away an object, the smaller the apparent parallactic displacement (shift). Recall how objects shift their positions when viewed from the window of a moving train. Telegraph poles fly by against the background of a distant wood; the landscape changes, but more slowly; the clouds, and particularly the sun, appear to be moving along with the train with no change at all in position.

The stars are unimaginably far away from the earth. That Copernicus was aware of. And therefore their parallactic shifts are so small as to be beyond detection. Neither Copernicus nor his immediate followers were able to detect any shift.

Then James Bradley decided to try his hand in this difficult field. He secured his telescope (with attached micrometer on the eyepiece) to the wall of a house and aimed it straight at the zenith. This was done on purpose because near the zenith there is less atmospheric distortion of celestial bodies. Of the bright stars near the pole of the ecliptic, only one, Gamma Draconis, passes through the zenith of Oxford every night. That is why Bradley chose this one for his parallactic measurements.

We shall not go into the details of this delicate and time-consuming job, which took about three years. The interesting thing was the result: Bradley discovered a periodic shift in Gamma Draconis; to put it more precisely, he found certain periodic variations in its equatorial coordinates. But it was definitely no parallactic shift. Firstly, it was too big (about 20″), secondly, the direction was not that to be expected. Later it was found that other stars as well experience such shifts during the year, and what is most remarkable, with the same amplitude of about 20″.

Bradley went in search of one thing and discovered quite another: an optical phenomenon that received the name *aberration of light*. Essentially it is this. Imagine you are standing under an umbrella in a downpour with the rain coming straight down. While you stand, the umbrella handle is in a vertical position, but as soon as you begin to run, your hand instinctively inclines the umbrella in the direction of motion.

Now compare that with a similar situation. Light rays are moving vertically from a star in the zenith to an observer

on the earth. Here, the telescope is the umbrella. If the earth were standing at rest, the telescope would remain pointed to the zenith. But the earth is in motion and the velocity of light combines with the velocity of the star relative to the observer. Due to this combination of two velocities, the light rays from the star will become inclined and the observer will see the star a bit shifted from the zenith in the direction of motion of the observer.

Bradley not only discovered a new phenomenon of nature, but also demonstrated experimentally that the earth does indeed move round the sun, for there would be no aberration if that were not so.

Another interesting sight in the Draco constellation is the remarkably bright planetary nebula located a short distance away from Zeta Draconis.

It is clearly visible in the large school refractor as a roundish relatively bright nebulous patch of the eighth magnitude. This nebula has the designation NGC 6543.

As early as 1864, the English astronomer Huggins chose the nebula in Draco as a test for the first spectroscopic observations of these mysterious objects. Spectral analysis was only taking its first steps when Huggins observed the spectrum of the Draco Nebula visually by attaching the spectroscope to the eyepiece of his telescope. And great was his amazement when in place of the customary rainbow band of the absorption spectrum, which is typical of most stars, he saw only three bright coloured lines against an absolutely dark background. Contrary to expectation, the Draco Nebula was found to consist of luminous gases and not stars. For the first time, the spectroscope demonstrated indisputably the existence in space of enormous clouds of rarefied luminous gases in addition to stars and planets.

Today we know many more interesting things about the Draco Nebula. For one, its distance: 1,000 parsecs, and its diameter: about 7,000 astronomical units.

The nebula is expanding in all directions from its nucleus, which is a very hot star of the eleventh magnitude visible in powerful telescopes at the centre of the nebula. This is one of the hottest known stars. It has a surface temperature of close to 57,000°.

We have been speaking of the expansion of the nebula, but remember that this is seen only by the shift of spectral lines. Outwardly, the nebula looks the same as in its

photograph—unchanged. Only centuries hence will astronomers get pictures of the nebula that are substantially different from today's photos. At a distance nearly all objects of the stellar world appear calm and immutable. Photographs reveal a complex inner structure of the Draco Nebula, which is not typical of the classical planetary nebulae like the one in the constellation Lyra. For this reason, the Draco Nebula is regarded as an anomalous planetary nebula.

Of the double stars in Draco, pay attention to three: Nu, Epsilon and Mu. Nu is in the head of The Dragon. It consists of two fourth-magnitude stars separated by an interval of 61″. This is an optical double that is readily distinguishable even in an opera glass. You can test the keenness of your eyesight by Nu Draconis: if you can resolve this star into two components on a dark transparent starry night, your vision is excellent.

And for the big school refractor there is an eyesight test (a test of resolving power) in the form of two other double-star systems. Both pairs are physical doubles, or binary systems. The primary in the Epsilon Draconis system is of Mag. 4.0; at an angular distance of 3″.3 it has a companion of Mag. 7.6. The star Mu Draconis consists of two components of equal brightness (Mag. 5.8) separated by an interval of 2″. The system has a period of close to 1,500 years.

Remember that these double-star systems are difficult objects even for the three-inch school refractor, and are much beyond the range of smaller instruments.

CAMELOPARDUS, The Giraffe

This constellation is distinguished by the fact that all its stars are fainter than the fourth magnitude. The only object that deserves attention in this asterism is a rather bright (Mag. 6) open (galactic) star cluster NGC 1502, only six minutes of arc in diameter. It is easy to find using binoculars, but only a large telescope shows it effectively.

LYNX, The Lynx

We have already had occasion to say that the constellation Lynx is the poorest region of the heavens, as far as stars go. True, the constellation has two stars brighter than fourth magnitude, but they are entirely uninteresting.

Just to test yourself in locating faint stars, try finding the position of Alpha Lyncis, an orange star of Mag. 3.2 located on the prolongation of the rear paws of The Great Bear. For astronomers of course there is no division into first-rate and second-rate stars. Everything observable is of interest. That is one reason why they have made such a thorough study of the spectrum of Alpha Lyncis, of its temperature, its motion in space; and they have found that this inconspicuous orange sun is distant from ours about 50 parsecs. Such information is built up not only for naked-eye objects, but for many thousands of suns that can only be reached by telescope. What difficult painstaking work! Astronomers strive not only to count the stars, but to fill in their star catalogues with all kinds of information about every single one. And there is good reason. Without these particulars, these details, we would never be able to build up a general picture of the stellar world. The great whole consists of multitudes of individual entities.

CONSTELLATIONS OF THE AUTUMN SKY

From the constantly visible circumpolar constellations let us now proceed to constellations that are characteristic of each of the four seasons: autumn, winter, spring and summer. This division into seasons is of course arbitrary. For instance, during the long winter nights one can see not only purely winter constellations, but autumn (early in the evening) and spring (just before morning) and even some of the summer constellations between evening twilight and sunrise. For this reason, let us agree to regard the night sky for specific days of the year and at one time of night. To illustrate, we shall regard the autumn night sky as the range of constellations open to the view of an observer on October 15 at 22 hours (10 p.m.) local time. For the winter sky we take January 15 at 22 hours, and for the spring, April 15 at 22 hours. For the summer sky (because we make an exception due to the white nights) we take July 15 at 23 hours. After this very necessary brief specification, let us take an overall view of the typical night sky of autumn (Fig. 31).

In the southern half of the sky, roughly over the south point, half-way from the horizon, we see an enormous square made up of four stars of about the same brightness. From its upper left corner is a tiny chain of three stars that curves eastwards and slightly upwards. On the whole, this seven-star asterism is a good deal like the dipper of Ursa Minor, only much bigger. The "Great Square" (minus upper left-hand corner) is the principal portion of the constellation Pegasus. The handle of the dipper is formed by the brightest stars of the constellation Andromeda.

There is another star of the same brightness as the main stars of Andromeda. It lies on the extension of the handle

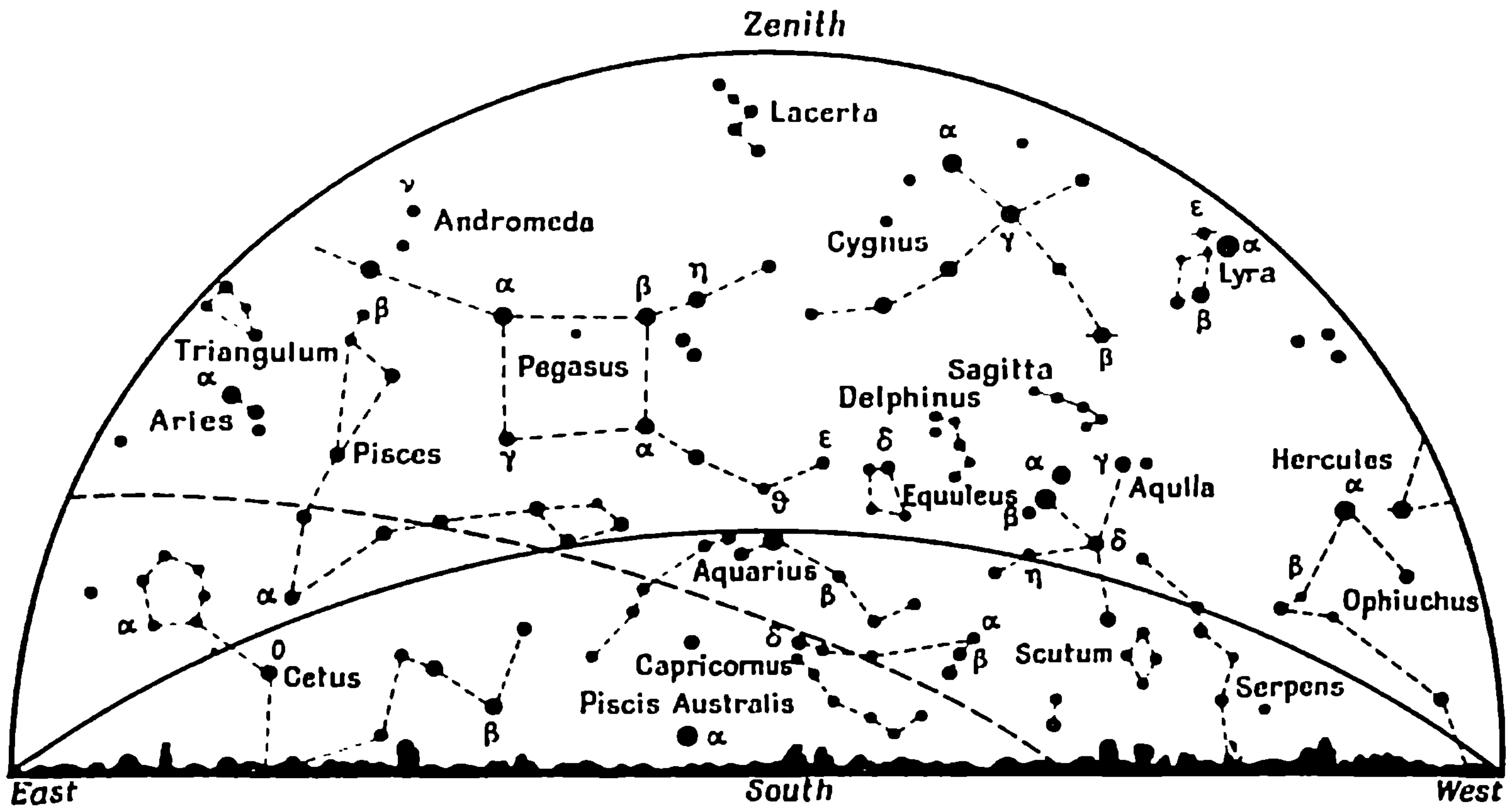


Fig. 31. Southern part of autumn sky.

and is the principal star of Perseus, Alpha Persei. The constellation itself features a triangle made up of the stars α, β, and δ.

Underneath the Andromeda chain of stars, in the south-eastern part of the sky, are two nearly equally bright stars that represent the constellation Aries. Pegasus, Andromeda, Perseus and Aries are the most prominent constellations of the autumn sky. The others can be found by proceeding from these most important constellations.

Between Andromeda and Aries lies a tiny constellation Triangulum. The triangle itself, composed of stars α, β and γ, is not conspicuous; what is more, a multitude of triangles can be constructed by joining up various triplets of stars.

Still less prominent is the constellation Lacerta, The Lizard, a group of faint stars bounded by the borderlines of the constellations Pegasus, Andromeda, Cassiopeia, Cepheus, and Cygnus. To the right of Aries is a large constellation, Pisces, which also lacks bright stars. Under Aries and Pisces is a rather big patch of sky occupied by the constellation Cetus, The Whale, the outlines of which even a fertile imagination cannot conjure up. The names of the autumn constellations have a variegated origin. Familiar heroes of mythology are evident in Pegasus, Andromeda, and Perseus. Just as ancient are the constellations Triangulum, Aries, Pisces, and Cetus. The sole significance of

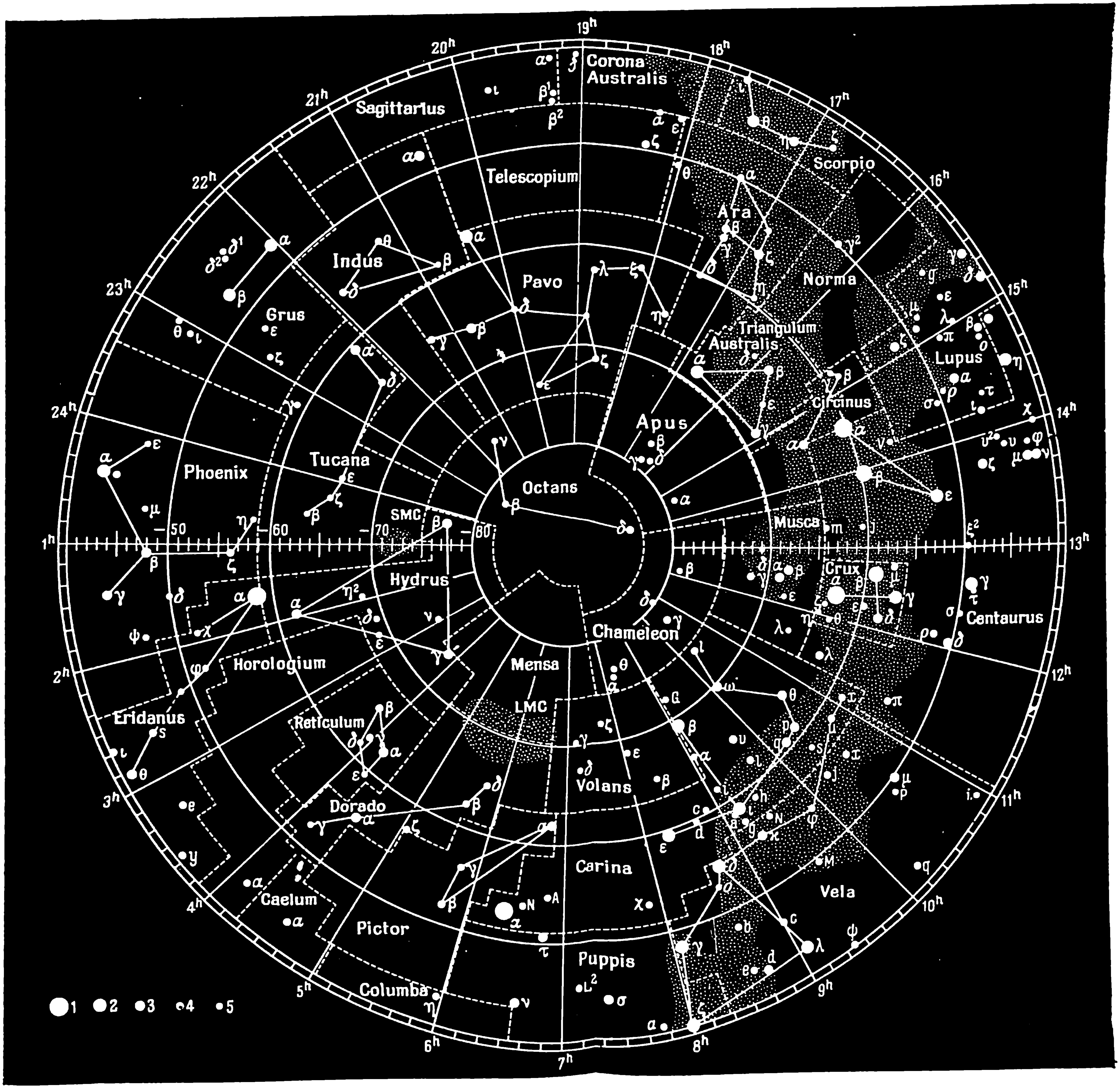
the first lies in its name. The same goes for Aries, which on ancient maps of the sky is depicted as a ram or lamb. Another strange sight on these maps is the constellation Pisces: two fish with their tails tied with a ribbon. According to one of the legends, in ancient times at the beginning of spring when the sun entered this constellation, there began a period of rain and floods, whence the reason for this uncalled-for name. The origin of the Cetus constellation is also rather obscure. The most popular legend was that in this region of the night sky the ancient Greeks immortalized the sea monster that almost swallowed poor Andromeda.

The constellation Lacerta is the product of unbridled fantasy, or, better still, the whim of the Danzig astronomer Hevelius. In 1690 Hevelius gave the name Lacerta, The Lizard, to a group of faint stars in this part of the sky. The reason? Simply because there was still space for a small animal, and the stars might be likened to scintillations on the scales of an elegant reptile.

PEGASUS, The Winged Horse

Like in many other constellations, the alpha star is not the brightest in Pegasus. It is somewhat fainter than Epsilon Pegasi, the brightest star of the constellation. To the right and just above this star is the main spectacle of the Pegasus constellation: a bright globular star cluster. Binoculars show it as a round luminous nebulous patch, but on a dark clear night the large school reflector reveals a wealth of structural detail. The patch is definitely round, but the surface brightness varies in different parts. The core of the spot is the brightest, and the brightness diminishes in all directions away towards the fringes. If you have good eyesight and some experience in astronomical observations, you will undoubtedly notice that the fringes of the patch scintillate like the lights of a distant city. Apply the averted-vision technique in these observations at the very limit of visibility.

In large telescopes, the globular star cluster of Pegasus is readily resolved into component stars. True, this has to do only with the edges of the cluster, and not the central regions where there are so many stars so densely packed that the eye of the terrestrial observer sees only a solid brilliance.



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Centaurus
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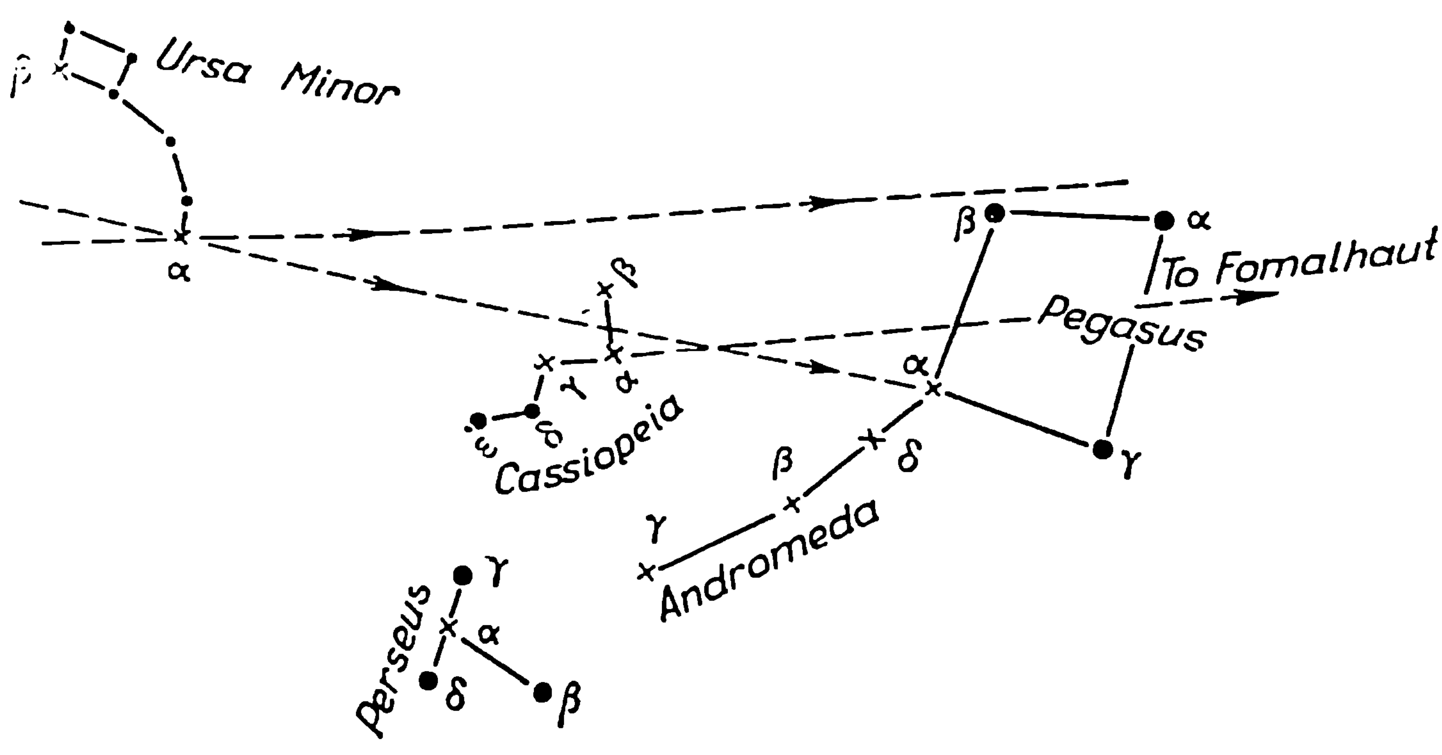


Fig. 32.

The globular cluster M15 (or NGC 7080) is one of the most distant: about 40,000 light years away. In the best photographs, the globular cluster of Pegasus has an angular diameter of 15 minutes of arc, which is half the disc of the moon! That enables us to compute that the actual diameter of this cosmic structure is close to 165 light years. It has been estimated that this sphere contains about six million suns. If there are inhabited planets somewhere in the centre of the cluster, their inhabitants see a sky quite different from ours. Tens of thousands of stars brighter than Venus studding the firmament and producing a picture of unimaginable beauty!

What remarkable structures are these globular star clusters, or, perhaps it would be better to say, spheres of stars. As yet unfathomed forces generated, out of pre-stellar matter, this enormous stellar system, which is something intermediate between double and multiple stars, on the one hand, and the giant galaxies, on the other.

Globular clusters are strangely inhabited. The predominant dwellers are giants; true, there are no particularly hot or supergiant types. But there are conspicuous cool reddish giants with surface temperatures of from 2,000° to 4,000°. Globular clusters have multitudes of variable stars, mainly Cepheids.

Although the star cluster in Pegasus, like most cosmic objects, appears to be static and unchanging, actually the situation is quite different. First of all, the cluster itself,

as a whole, is in motion and its spectrum indicates that it is approaching us at the rate of 114 km/s. Also, each star of the cluster describes a fanciful curve about the centre and poses one of the most involved of all modern problems of celestial mechanics. Finally, certain globular clusters are somewhat flattened, which is a definite sign of axial rotation of the whole "sphere of stars".

Globular star clusters are one of the oldest objects of our Galaxy. They have extremely high stabilities and can go on existing without disintegrating for millions upon millions of years!

The right upper corner of the "Great Square" of Pegasus, Beta Pegasi, is intriguing. Just a short time ago, it was listed in catalogues of variable stars as an unknown type. Now the matter has been fully cleared up. The red giant Beta Pegasi is an *irregular* variable with a brightness oscillating from Mag. 2.4 to 2.8. We thus have another type of stellar variability, perhaps one of the most complicated, due to the fact that there does not seem to be any law governing the variation of brightness. It may be that in stars of this type (red irregular variables), slight fluctuations of surface temperature bring about perceptible oscillations of their atmospheric transparency. In these relatively cool atmospheres there are clouds of titania, the optical properties of which (transparency) are very sensitive even to small fluctuations of temperature. This is only a hypothesis, of course, and may be very far from actuality.

ANDROMEDA

The Arab astronomer Al-Sufi, living in the tenth century A.D., described a "small celestial cloudlet" that is easy to see on dark nights near the star ν of the constellation Andromeda. In Europe attention was brought to this object only in the seventeenth century when astronomer Simon Marius, a contemporary of Galileo and his helper in the first telescopic observations of the sky, scrutinized this strange celestial nebula in December 1612. Wrote Marius, "The brightness increases as one approaches the central portion. It resembles a lit candle if looked at through a transparent horn plate."

Several decades later, the nebula in Andromeda was studied by Edmund Halley, friend and pupil of the great Newton. In his opinion, small nebulous patches are nothing

other than light coming from unmeasurable space located in the regions of the ether and filled with a spread-out self-luminous medium. Other astronomers, of a religious bent, like Durham, insisted that in this spot, the "celestial crystalline firmament" is somewhat thinner than usual and for this reason unuttered light streams from the kingdom of heaven onto the sinning earth.

The true nature of the Andromeda Nebula was not deciphered in the nineteenth century either. The "celestial firmament" was then forgotten, but heated debates raged about whether the nebula was made up of luminous gases or stars, whether it lay outside our stellar system or within the vicinity of the sun giving birth to a new planetary system.

As is the rule in such cases, the problem was resolved when new and powerful tools of investigation appeared. In 1924 Edwin Hubble, the noted American astronomer, resolved the Andromeda Nebula into its component stars with the 100-inch reflector of the Mount Wilson Observatory. For the first time, astronomers looked upon a magnificent stellar system with thousands of millions of suns and, perhaps, millions of inhabited planets—in short, a neighbouring galaxy.

Resolution of the Andromeda Nebula into separate stars immediately solved the problem of distance from the earth. What had proved too difficult to do with respect to the nebula as a whole became a relatively simple task as regards the component stars. Utilizing the physical properties of some of them, it was demonstrated quite cogently that the Andromeda Nebula does not lie within our Galaxy, but a great distance beyond: 520 kiloparsecs according to the latest estimates. That is how *extragalactic astronomy*, one of the most rapidly developing branches of the science of the sky, got started.

The Andromeda Nebula is the only galaxy visible to the unaided eye. It has a magnitude of 4.3. On dark nights this "nebulous star" is rather conspicuous and can be located without especially keen sight.

The nebula appears as a small oval-shaped luminous patch whose greatest diameter is about 1/4 of a degree (15′). But this is not the entire nebula, only the central portion, which is the brightest. Good photographs of the Andromeda Nebula picture it with much greater dimensions: close to

Fig. 33. Andromeda Nebula.

160′ in length and about 40′ in width (Fig. 33). In other words, the nebula covers an area nearly seven times that of the lunar disc! And still this is not the whole nebula. Microphotometers (instruments used to measure the black areas in negatives of astronomical objects) perceive the action of light on emulsion where the eye sees nothing. Applied to the negatives of the Andromeda Nebula, it broadened

the image of this unique structure to the "astronomical" dimensions of 270′ (or 4°.5) in length and 240′ (or 4°) in width! This means that the Andromeda Nebula occupies an area in the sky of 14 square degrees, or 70 times the extent of the full moon! If our vision were as sensitive as microphotometers, the Andromeda Nebula would appear about the size of one-third the dipper in Ursa Major.

A certain smearedness (a dwindling decline) round the fringes is characteristic of all galaxies. This suggests that intergalactic space is not empty at all, but is filled with a tenuous medium called the intergalactic plasma. Generally speaking, it is even more natural to presume that galaxies are condensations in the ubiquitous all-permeating material medium that completely fills the observable part of the universe.

There is yet another point of interest. The Andromeda Nebula appears to our eye as an oval patch, but the microphotometer sees it as nearly spherical. This property of the Andromeda Nebula makes it akin to our own Galaxy and to other spiral stellar systems. Their flat lens-like shape is only apparent. To be more precise, the flat disc forms only the chief portion of the stars of the Galaxy. A considerable portion makes up a spherical-like veil, a very transparent "sphere" that includes the equatorial "lens" as well.

The Andromeda Nebula is the best studied of all known galaxies. We know structural details of this "island universe" that most likely are not known to the intelligent beings within it.

The Andromeda Nebula is a gigantic stellar spiral 27 kiloparsecs across, which we see neither flat- or edge-on, but half-turned, so to speak. Our own Galaxy, the Milky Way, appears just about the same from the Andromeda Nebula.

The two galaxies have much in common. Enormous spiral arms of stars emerge from the huge central sphere-shaped condensations of predominantly yellow dwarf stars (the nuclei of galaxies). On recently obtained excellent coloured photographs of the Andromeda Nebula, the arms appear bluish in contrast to the yellowish central nucleus. This is quite natural because the nucleus is made up chiefly of yellow stars like our sun, whereas the silhouette of the spiral arms is due to hot blue-white giants.

New stars, novae, periodically flare up in the Andromeda Nebula, numerous Cepheids twinkle brighter and fainter in oscillation, and there are undoubtedly many more familiar classes of variable stars. In 1885 there was even an outburst of a supernova, which shone for a short time as brilliantly as a thousand million stars of that galaxy!

Inside the Andromeda Nebula and round about it are some 140 globular star clusters registered to date that are very much like similar objects of our own Galaxy. This neighbouring galaxy also has galactic star clusters and gaseous nebulae and clouds of minute particles of cosmic dust. These clouds explain the numerous dark gaps, against the otherwise luminous stellar background, that are clearly seen on photographs of the Andromeda Nebula.

The stars of the Andromeda Nebula revolve about the central nucleus just like the stars of our own stellar system. One should not take the term "rotation" too literally. Galaxies like the Andromeda Nebula do not rotate as a whole, like, say, a phonograph record. On the other hand, we cannot picture the motions of the stars as completely analogous to those of planets of the solar system. Reality lies some place between these two extremes: the rotation of a solid body and the Keplerian revolution of the planets. In the Galaxy, the angular velocity of rotation diminishes with increasing distance from the centre, but more slowly than by Kepler's laws. That is only the most general picture of the revolution of spiral galaxies. The details are very complicated and have not yet been fully resolved.

It may be that some of the stars in the Andromeda Nebula have planets with intelligent beings, particularly since there are so many stars of the same type as our sun. If there are centres of civilization, they are most likely concentrated in the nucleus of the nebula which consists of solar-like stars. The mean distances between individual stars are much smaller than in the arms of the spiral and this would simplify communication between civilizations. Who knows, perhaps thinking beings in the nucleus of the Andromeda Nebula have long since established the Great Circle of Cosmic Commonwealth which was spoken of in such glowing terms in the "Andromeda Nebula" of the Soviet writer and scientist I. Efremov.

The Andromeda Nebula is surrounded by a retinue of four much smaller stellar systems. The chief one, an el-

liptical galaxy, M32 visible in the large school refractor was discovered as far back as the eighteenth century. It is about 0.8 kiloparsec across and has a population of roughly a thousand million stars. Just as sparsely populated is another dwarf galaxy, NGC 205, though it is twice the size of the former. The other two companion galaxies, discovered only in 1944, are very much like these. Alongside such tiny stellar systems, the Andromeda Nebula and our Milky Way are simply giants. But that shouldn't make us self-complacent in any sense, for the number of recorded giant galaxies is already in the millions.

The Andromeda constellation has yet another splendid sight—the triple star Gamma Andromedae, to which the Arab astronomers gave the name Alamak. The primary, a yellow second-magnitude star with an orange tinge, has a fifth-magnitude companion star at a distance of 10″. The companion—a hot bluish star—itself consists of two components separated by a distance of 0″.3. This latter pair is undoubtedly related physically: it has long since exhibited orbital motion with a period of 56 years. This double system is not resolvable in school-type telescopes, but the first pair is a beautiful double star with highly contrasting colours of the component stars that are greatly enhanced by physiological effects. It might very well be that this too is a physical double (binary), but no orbital motion has as yet been detected.

Alamak and its double component are very far away from the earth—125 parsecs.

Omicron Andromedae is another interesting star, a variable of unknown type with a brightness that fluctuates between Mags. 3.5 and 4.0. Judging by the spectrum, Omicron Andromedae consists of two hot stars whirling about a common centre of gravity with a period close to one and a half days.

PERSEUS

On old star maps, Perseus is depicted in a warrior-like attitude. In his right hand he holds high a sword, and in his left the terrible head of Medusa. Observing the heavens in the Middle Ages, the Arabs noticed that one eye of Medusa was fixed and steady, while the other varied in brightness from time to time. Struck by this spectacle, they called the

"winking" eye of Medusa the Demon Star (Algol in Arabic). This is Beta Persei.

In Europe the variability of Algol was first noticed in 1667 by the Italian astronomer and mathematician Montanari. True, he was not able to figure out the law of variation of brightness in Algol. This was done by John Goodricke. On every clear night between 1782 and 1783 he estimated the brightness of Algol and succeeded in establishing a rigorous periodicity in the twinkling of the eye of Medusa.

For two and a half days Algol maintains a constant brightness of Mag. 2.2. But then during nearly nine hours the brightness declines to Mag. 3.5 and then again rises to its former level. The time interval between two successive minima of this variable star is close to 2 days 21 hours (the latest data indicate that Algol has a period of 2 days 20 hours 45 minutes 55.65 seconds).

Goodricke did not confine himself to this alone. He gave a perfectly correct explanation of the variability of Algol. He said that if it weren't too early to attempt to reason about the causes of this variability, he would presume the existence of a larger body revolving about Algol.

For about two hundred years this brilliant conjecture of Goodricke remained only a hypothesis. But in 1889 the spectrum of Algol revealed periodic displacements of the spectral lines with a shift period exactly coinciding with the period of variation of brightness. This was final proof that Algol is a spectral binary star and the fluctuations of brightness are due to periodic eclipses of the primary by its companion.

Algol was the first eclipsing variable star discovered. To date, about 2,000 such stars have been recorded. Quite naturally, Algol is the best studied of them all. We know many remarkable things about this luminary.

Fig. 34 shows the light curve of the Demon Star. To the uninitiated it tells but little, but to the astronomer it is extremely eloquent.

You probably notice that between the two principal minima (of a "depth" of Mag. 1.27) there is a smaller secondary minimum. The eye does not perceive it (because of a "depth" of only Mag. 0.06), but modern astrophotometric techniques reveal a secondary minimum. This means that Algol's companion star is not altogether dark, but only shines less brightly than the primary star. Then the light

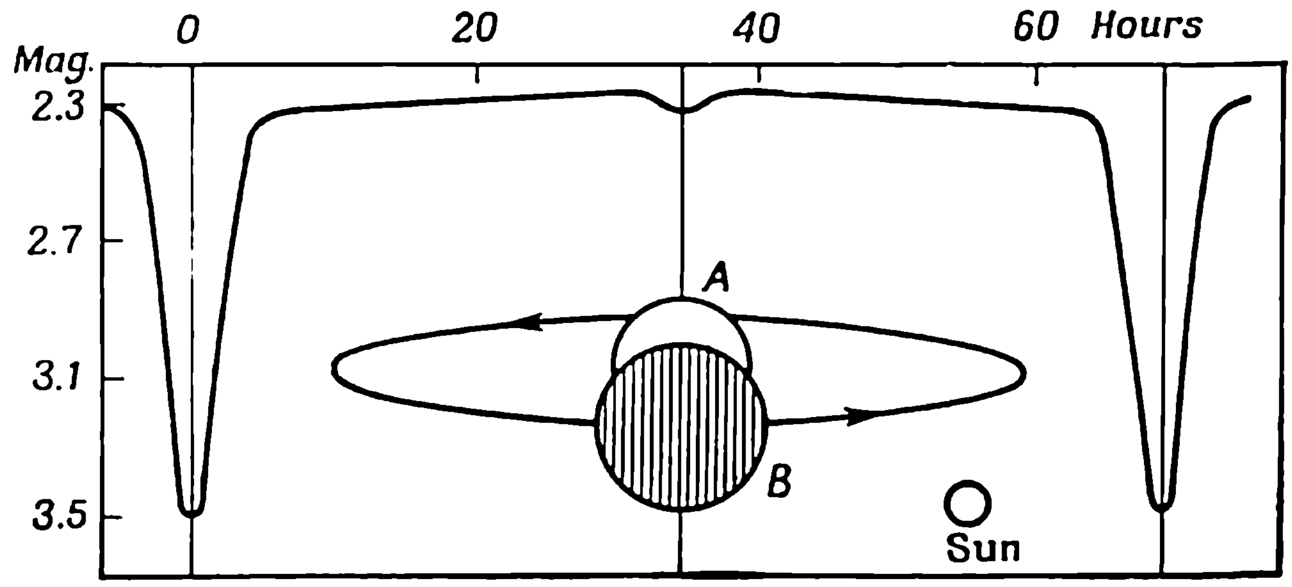


Fig. 34. Brightness variation of Algol.

curve will reflect both eclipses: when the primary is partially blotted out by the companion star (main minimum) and when the companion goes behind the primary (secondary minimum). In both cases there is a diminution (true, in varying degrees) of the total brilliance of the system.

Let us take a closer look at Fig. 34. The brightness of Algol changes somewhat from primary to secondary minimum and back again: the light curve first goes upwards and then, after the secondary minimum, down again. This is known as the *phase effect*. The analogy with the lunar phases or, more completely, with the phases of the inferior planets, is obvious. The primary star illuminates the darker companion, and on it (despite its luminescence) arise continuously varying phases. That, strictly speaking, is why Algol is constantly changing in brightness.

The limited scope of this book does not allow us to take up other fine effects that are reflected in the curve of brightness variation of eclipsing variables. But it may be added that for Algol-type stars we are able to compute the orbits of the components, their dimensions, masses, densities, and many other properties. Here are a few particulars about Algol: the primary star is a bluish-white giant with a surface temperature of about 15,000°. It has a diameter of 5,800,000 km (compared to the sun's 1,391,000 km). The companion is somewhat smaller (being about 4 million kilometres in diameter) and cooler. But this is a typically yellow star with surface temperature of about 7,000°, which is 1,000° hotter than the surface temperature of the sun. Isn't it

amazing that a phase effect can occur on such a brilliant surface?

Note also the fact that the temperature difference of several thousand degrees is quite sufficient to produce this *eclipse effect* which we perceive with the naked eye without any additional photometric devices.

The distance between the centre of Algol and its cooler companion is nearly 10,400,000 km (by contrast, the radius of Mercury's orbit is close to 58 million km). Fig. 34 shows the orbit of the companion about the primary star and the components of the system relative to the sun.

The masses of the two stars have been computed with the aid of the generalized law of Kepler. The companion star is of the same mass as the sun, while the primary is 4.6 times as massive. And both stars are extremely tenuous. The mean densities of Algol and its companion (compared with the mean density of the sun taken as unity) are 0.07 and 0.04, respectively.

It has long been noted that the period of variation of brightness of Algol is not constant. It fluctuates within a narrow interval but in a very complicated fashion. The reason was found just recently: this remarkable Demon Star is not a double but a triple star! Algol has a third distant companion with a period round the primary of 1.87 terrestrial years. The plane of its orbit is such that it does not cause any eclipses. But it gives rise to perturbations in the motion of Algol and the first companion star; these in turn produce oscillations of the period. A truly amazing star this twinkling eye of Medusa: a spectral-triple and eclipsing variable star distant from the sun 32 parsecs.

There is another bright variable in this constellation, Rho Persei. This is a red cool star, a semiregular variable. Its brightness fluctuates between Mags. 3.2 and 3.8. It has a rather clear-cut period of 33 to 35 days, onto which are perhaps superimposed certain long-period fluctuations of brightness with a period of about 1,100 days.

Half-way between the stars Alpha Persei and Delta Cassiopeiae is one of the most beautiful open star clusters. The eye sees an elongated luminous patch of irregular outline. Take a low-power telescope and you will see a marvellous cluster of stars. Hundreds of scintillating points are haphazardly scattered about the field of view. It is immediately evident that the cluster is a double system

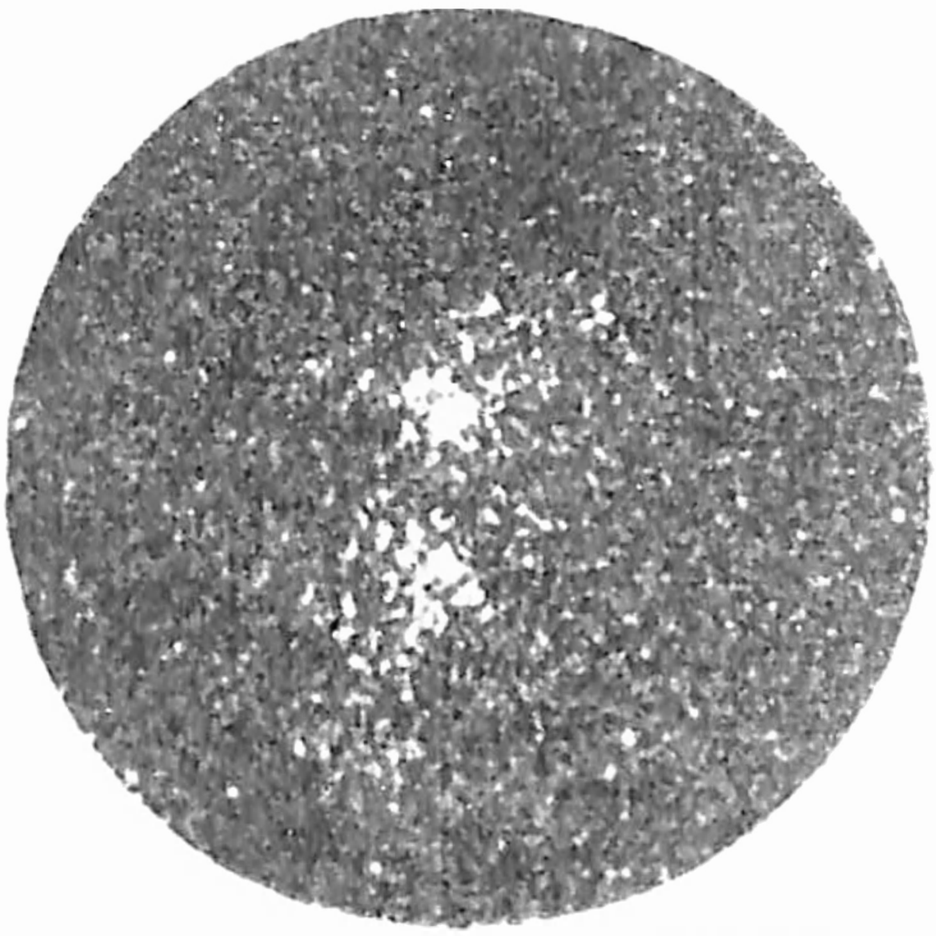


Fig. 35. Open star clusters χ and h Persei.

with two centres of stellar condensation. That is why it is designated with two letters χ and h Persei (Fig. 35).

Although both clusters appear equally distant from the earth, they aren't. Cluster h is 1,900 parsecs away, and cluster χ is 2,000 parsecs distant. They have nearly the same linear diameters: 17 parsecs in the case of h and 14 parsecs in the case of χ. Of the bright open star clusters, these two have the biggest populations: cluster h has about 300 stars, and cluster χ about 200. As has already been pointed out, star clusters are not fortuitous aggregates of stars encountered in a limited portion of space (the probability of such an event is close to zero), but a commonwealth of objects generated jointly out of some kind of pre-stellar forms of matter.

The prominent Soviet astronomer Academician V. Ambartsumyan demonstrated, as far back as 1947, that certain of these stellar groups, *stellar associations**, are very young by cosmic standards; in other words, the process of star formation is still continuing today.

* Stellar associations are groups of relatively close-lying (10 to 100 parsecs) stars of a similar, comparatively rare type.

It is a remarkable fact that the clusters χ and h Persei are the central portion, a sort of nucleus, of one of the best known stellar associations. In the cosmic environs of these clusters, at distances reaching to about 10 diameters of each of them, a relatively large number (75) of supergiant hot stars have been discovered. These stars are rare in any case, and such a combination of them in a relatively small region of space is obviously not fortuitous. An accidental encounter of 75 stars in this part of our stellar city with its population of 150 thousand million suns is just as improbable as a chance meeting of 75 acquaintances on the streets of Moscow.

This means that the association in Perseus (like other stellar associations) is a group of jointly formed stars. If the association consists mainly of very hot supergiant stars, it is called an O association. Characteristic of O associations is that they have one or several "nuclei", the role of which is often played by open star clusters made up of hot stars. The clusters χ and h Persei are just such hot clusters. Perseus has yet another O association grouped about the supergiant hot star Zeta Persei. This association also includes a small open star cluster located near the star.

The second O association in Perseus, or Perseus II, as it is conventionally known, is less numerous than the first. It consists of only 12 stars, including the very hot white star Xi Persei (the surface temperature is close to 30,000°). This closest stellar association (only 290 parsecs away) has the following dimensions in the picture plane: 50×30 parsecs.

In 1953, the Dutch astronomer Blauw discovered that the component stars of the association Perseus II are racing away in all directions from the central part. Take a look at Fig. 36, which shows the association Perseus II. The arrows indicate the direction of motion, and the lengths correspond to the distances these stars will have covered in the sky in 500,000 years from now.

Blauw estimated that the mean velocity of expansion of the Perseus II association is close to 12 km/s. This then suggests (via simple computation) that roughly 1,300,000 years ago the stars of the association were concentrated in a very small, practically point-like, volume of space. In other words, the Perseus II association originated approximately 1,300,000 years ago. This is a very short time

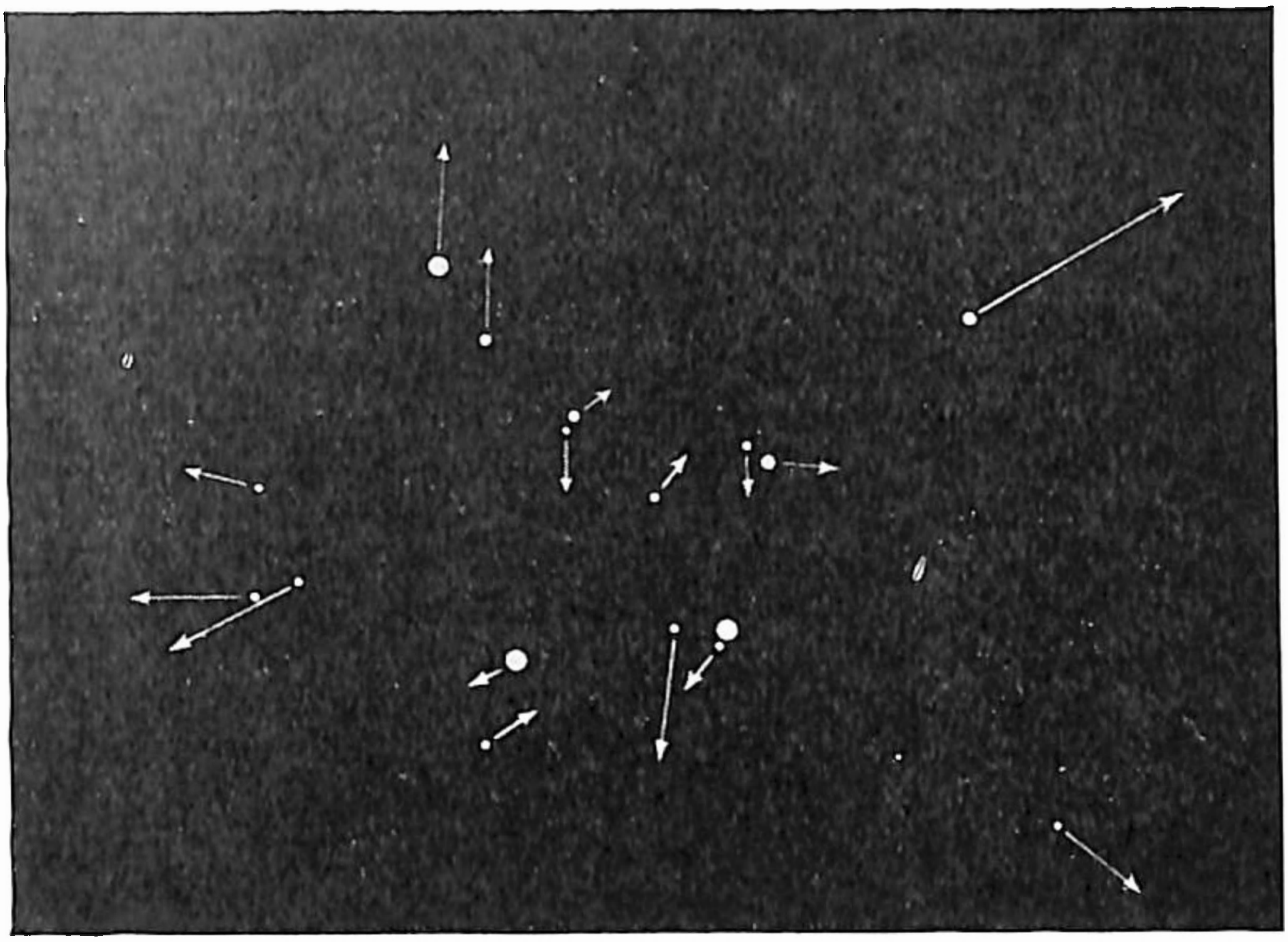


Fig. 36. Star association Perseus II.

when speaking of stars. If we consider that stellar lifetimes are measured in tens of thousands of millions of years, the stars of the Perseus II association must be viewed as newly born infants. On the scale of a human lifespan (say 70 years), the age of association stars corresponds to the first day of an infant.

Turn your binoculars to this part of the sky and take a look at these new-born stars. Not a single telescope shows us stars that could be considered the "parents" of stellar associations. Academician Ambartsumyan adduces cogent arguments to support his view that these as yet unknown pre-stellar bodies that nobody has ever observed should have colossal reserves of energy within small dimensions and fantastic densities. Some estimates suggest that a piece of pre-stellar matter the size of a pinhead should weigh hundreds of thousands of tons. Such are the extraordinary objects that the constellation Perseus, or rather, more properly, its two stellar associations offer us.

ARIES, The Ram

The constellation Aries is poor in objects of interest. Yet there is a thing or two.

One of the features of the Aries constellation is the triple star α, β, γ, which is conspicuous on the surrounding background of faint stars. Gamma Arietis is a binary star made up of practically twin components. They are hot white-blue stars with a surface temperature of about 11,000° and are separated by an angular distance of 8″, making this pair an easy object even for school telescopes.

It is noteworthy that Gamma Arietis is the first telescopically discovered double star. Its double nature was discovered in 1664 by the famous physicist Robert Hooke. In this connection he wrote that it consisted of two tiny stars very close together and that he had never before encountered such a thing in the heavens.

Another interesting sight is the double star Lambda Arietis, which consists of a fifth and an eighth magnitude star separated by 38″. Since 1781, when their relative positions were first measured, they have remained fixed in relation to one another. But they are both moving in the same direction in space and with the same velocity, which can hardly be accidental. In such cases it is common to say that the orbital motion is not noticeable due to the very great periods of revolution.

TRIANGULUM, The Triangle

This tiny constellation with only 15 naked-eye stars has one of the closest and best studied galaxies, M33. Look for it to the right of Alpha Trianguli in the approximate direction of Beta Andromedae, or Mirach (Fig. 37).

The reader must be warned that the M33 galaxy is not easy to locate. Although it is the brightest galaxy after the Andromeda Nebula (its integral brightness being equal to that of a magnitude 6.2 star), its surface brightness is low and it should be observed only on the darkest of nights.

In the school telescope you will see a tiny circular luminous dot without any detail. Remember that at this instant your eye is receiving rays that this distant (though neighbouring) stellar system sent off 1,800,000 years ago!

The M33 galaxy is a splendid sight on good photographs

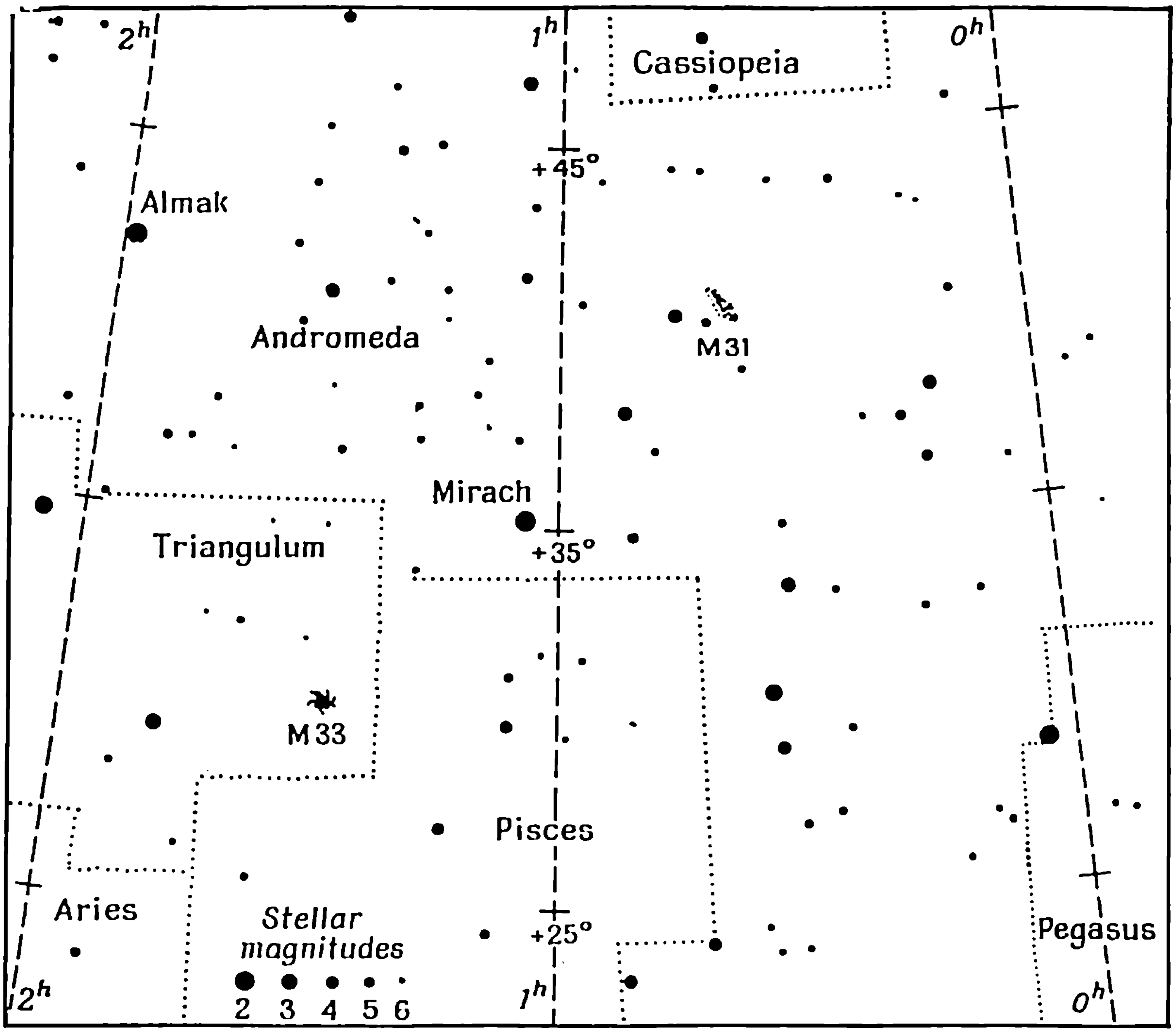


Fig. 37. The M33 nebula in the Triangulum constellation.

(Fig. 38). We see it nearly flat, its spiral arms beautifully displayed. They are much more developed than in the Andromeda Nebula or in our Galaxy. The nucleus of M33 occupies a correspondingly smaller volume.

The galaxy in Triangulum is only about a third the diameter of the Andromeda Nebula, which has about 100 times the number of stars of the former. The Triangulum galaxy has revealed about 50 variables, mostly Cepheids. It also has gaseous nebulae, whose spectra resemble very closely our own galactic nebulae. The nucleus apparently concentrates mainly hot stars, which distinguishes M33 from the Andromeda Nebula and from our own Milky Way.

It is interesting to note that in photographs taken with a red filter the M33 galaxy appears smeared and completely loses its spiral structure. Which is not surprising, since the spirals consist of hot stars that radiate bluish rays of

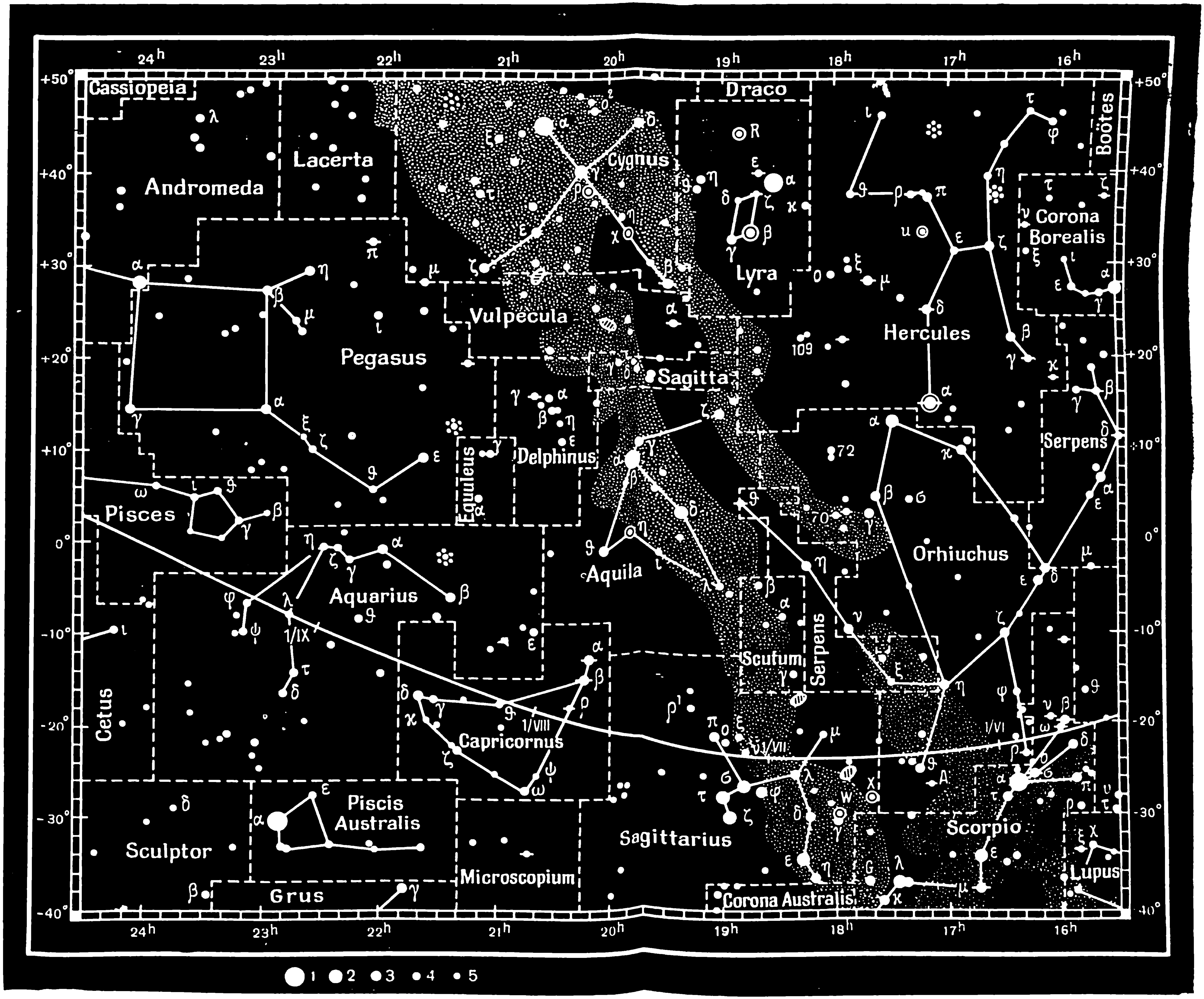
Fig. 38. A photograph of the M33 galaxy.

short wavelength, while the spherical "halo" about a spiral galaxy (and this goes for M33 as well) includes a multitude of red giants. They are the ones that produce the solid veil on photographs in red light, blotting out the spiral silhouette of M33. This instance illustrates the fact that galaxies (and other objects as well) look different in different light.

PISCES, The Fishes

The principal star, Alpha Piscium, is at the same time its chief sight. Binoculars readily show Alpha Piscium to be a hot blue star with a surface temperature of about 10,000°. Its magnitude is 4.3. At a distance of 2″.65 from the primary star is a companion that is just as hot but somewhat smaller in size (Mag. 5.2). It is difficult to resolve this pair in the large school refractor, but under favourable conditions it is still possible.

This is a binary star with a period of 720 years about the common centre of gravity. Spectral analysis has demonstrated that each of the components is in turn a spectral binary. Here again we have a quadruple star (multiple star). Four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+50° +40° +30° +20° +10° 0° -10° -20° -30° -40°
Cassiopeia
Andromeda
Lacerta
Cygnus
Draco
Lyra
Hercules
Boötes
Corona Borealis
Vulpecula
Pegasus
Sagitta
Delphinus
Equuleus
Serpens
Pisces
Aquila
Orhiuchus
Aquarius
Cetus
Scutum
Serpens
Capricornus
Sagittarius
Scorpio
Piscis Australis
Sculptor
Microscopium
Grus
Corona Australis
Lupus
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suns physically related and divided into two couples circling about a mathematical point called the centre of gravity of the system. And the same laws of celestial mechanics operate in this distant group of four suns (40 parsecs away) as in our own solar system.

CETUS, The Whale

The constellation Cetus is one of the largest in the sky. It comprises exactly 100 stars visible to the unaided eye. Which of them is the brightest? Rather a simple question, it would seem, but the answer is not quite ordinary: it all depends on the time. Things change, and at different times we get different results. The clue to this peculiar situation lies in the fact that the brightest (at times, that is) star in the constellation Cetus is a variable star.

This was first noticed by a contemporary of Galileo and one of the best observers of that period, David Fabricius. The discovery was made quite by accident. On the morning of August 13, 1596, Fabricius was engaged in observing Mercury. There were no telescopes in those days and he was about to measure the angular distance between that planet and a third-magnitude star in the Cetus constellation. He had never seen the star before and did not find it on any star map or globe. Incidentally, both maps and globes were inaccurate, and to miss some rather faint star was not really an exceptional case.

Still, being a conscientious observer, Fabricius began to follow this star. By the end of August it had reached a magnitude of 2, but in September it became faint, and in the middle of October disappeared completely. Being fully convinced that this was a nova like the one observed by Tycho Brahe in 1572, Fabricius ceased observations.

You can imagine his amazement thirteen years later, in February of 1609, when he again saw this remarkable star.

By the middle of the seventeenth century it was finally established that the mysterious star of the Cetus constellation is a variable with a very long period of brightness fluctuation and a large amplitude. Thus the Europeans discovered the first type star of a new class of *long-period* variable stars. Hevelius gave the name Mira (The Wonderful) to this unusual star of Cetus. The physical properties of Mira fully justify the name.

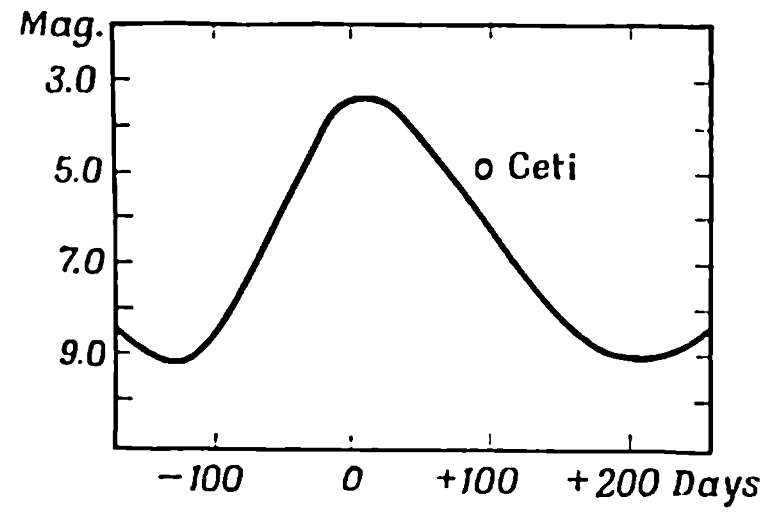


Fig. 39. Light curve of Omicron Ceti.

Mira Ceti (Omicron Ceti) changes in brightness between Mags. 3.4 and 9.3. Which makes it one of the brightest stars in the constellation at maximum brightness, and even beyond the reach of binoculars at minimum (Fig. 39).

These figures are mean values of the brightness of Mira at times of maximum and minimum. On occasion, however, Mira becomes a second-magnitude star, or the brightest in the constellation Cetus. And there are cases when at minimum brightness it declines to Mag. 10.1.

Neither is the period constant. It has an average of 331.62 days. From period to period there is a perceptible change in the shape of the light curve. This variability of Mira and other long-period variables distinguishes them from the Cepheids with their almost stable periods and light curves.

Both Mira and all other variables of this type are without exception cool red giants with very low surface temperatures (about 2,000°). Their atmospheres are so cool that the spectra of long-period variables contain abundant absorption bands of a variety of chemical compounds (titania and circonia, for example). These compounds are extremely sensitive to even slight fluctuations of temperature, which immediately find expression in oscillations of band intensity. It is precisely for this reason that fluctuations of brightness in long-period variables have a very great amplitude in visible rays, whereas the total radiation of the star varies but slightly.

At maximum brightness, the spectra of Mira and similar stars exhibit bright emission lines of hydrogen and certain metals. At minimum brightness, they turn into absorption

lines. Long-period variables pulsate like the Cepheids, as witness the periodic shifts in the lines of their spectra.

How are we to account for the variability of Mira and the other stars of this class? When red giants pulsate, their surface temperatures vary as well, which immediately affects the optical properties of the atmospheres (this does not occur in the hotter Cepheids). As the temperature rises, the chemical compounds disintegrate and the atmospheres become more transparent; cooling reverses the process. A certain role is also played by the hot hydrogen masses which at maximum brightness are ejected into the atmosphere and increase the brightness of the star (they are the ones that produce the bright emission lines of the spectrum). That is the most likely explanation of the remarkable changes exhibited by Mira Ceti. In 1919 it was noticed that a second spectrum belonging to some very hot white star is superimposed on the Mira spectrum. Four years later, a 10th-magnitude hot companion star was discovered right next to Mira, at a distance of only $0''.9$. It apparently makes a complete circuit about the primary in a few hundred years. It has been suspected that this companion is in turn a variable star of an unknown type. This tight association of two utterly different stars (different as to physical characteristics), and variables to boot, is an extremely curious fact.

We can only rejoice in the fact that our sun does not belong to the class of long-periodic variables. In the visible part of the spectrum, Mira's radiation varies some hundredfold from maximum to minimum. With solar emission fluctuating in that manner, the organic world of the earth would most likely perish. There is hardly any chance, therefore, that Mira and other similar stars have inhabitable planets about them.

In the constellation Cetus you will find a bright star of Mag. 3.5 which is quite different. Tau Ceti has come to the fore in recent years and is easy to find on any star map.

Tau Ceti has a very high proper motion, covering nearly $2''$ across the sky in one year. This is a sure sign of proximity to the earth. True enough, Tau Ceti is one of the nearest stars. Only 12 light years away.

Tau Ceti is a yellow dwarf much like our own sun, but slightly smaller and cooler. Like the sun, it too apparently rotates slowly on its axis (the sun's rotational period is close to a month). The hot stars of spectral class A and other

"earlier" types rotate very rapidly, hundreds of times faster than the sun. Beginning with stars of spectral class F, there is a sudden jump in rate of rotation. There is considerable support for the view that this jump is due to the effect of planets in orbit round the cooler stars. These planets take up the major portion of the total motion (angular momentum), just like in the solar system, and for this reason the mother stars have a very slow rate of axial rotation.

These are the reasons which suggest that Tau Ceti is not only outwardly similar to the sun, but perhaps has inhabitable planets as well. The suspicion is so strong that for several months the radio telescopes of American astronomers have been tuned in to Tau Ceti in the hope of receiving some kind of radio signals from our distant "intelligent brothers". So far the cosmos is not talking, but who can say that this audacious endeavour will not culminate in a brilliant discovery that could usher in a totally new epoch?

Meanwhile, it is definitely worth locating Tau Ceti in the sky and getting a good view of this cousin sun of ours that may be tending a distant civilization very much like our own.

LACERTA, The Lizard

There is not much of interest here. The constellation has only one star brighter than fourth magnitude and only 35 stars visible to the naked eye.

The principal star, Alpha Lacertae, is a hot blue giant 28 parsecs from the earth. It is definitely no sight because astronomers have multitudes of this kind. But still Lacerta has a thing or two to tell us.

In the summer of 1936 I was returning from Kazakhstan where I had observed a total solar eclipse in the expedition of the Moscow Section of the USSR Astronomic-Geodetic Society. In the train we learned that at the very same time, our colleague in the Society, Sergei Norman, had discovered a nova in the constellation Lacerta.

I remember very well this tall modest blue-eyed Moscow schoolboy, a great devotee of astronomy. He specialized in observations of variable stars. Like any other "variable man", Norman knew his constellations well. He immediately noticed a bright new star that flared up in the constellation Lacerta. Unfortunately, Sergei Norman was

not able to make his dream come true and become a professional astronomer (he soon died of a grave illness), but his name will not be forgotten by those who love the science of the sky.

Nova Lacertae 1936 reached Mag. 2.1, becoming brighter than the stars of the dipper of Ursa Major. There have been no brighter novae since then. Having attained maximum brightness, this typical nova gradually declined, finally falling to Mag. 15.3. Now the former nova can be found only in the most powerful modern telescopes. There is every probability that some centuries hence it will again flare up—typical novae (apparently unlike supernovae) have repeated outbursts. Who will be first to see the fresh flare-up of Sergei Norman's star? What unimaginable heights will the technology of terrestrial civilization have reached by then?

It is my desire that this little episode should spark readers to study variable stars, for this is a division of astronomy where with small expenditures (but with great persistence and patience) the amateur astronomer can make fundamental scientific discoveries.

CONSTELLATIONS OF THE WINTER SKY

The starry sky is perhaps never so beautiful as in winter. The secret lies not only in the transparency of clear frosty nights, their long duration and in the blackness which so contrasts with the whiteness of the earth's snowcover. The winter night sky is rich in bright stars and impressive constellations.

Mid-winter, February 15, at 10 p.m. (or 22 hours). In the southern part of the sky, just a bit to the left of the celestial meridian is the conspicuous giant figure of the legendary hunter Orion. His belt displays three hot white stars ζ, ε and δ, and on his right shoulder is the brilliant reddish star Betelgeuse. Although this star is Alpha Orionis, it is not the brightest star of the constellation. It is Rigel, or Beta Orionis, that is brightest (Fig. 40).

On old star maps the celestial hunter Orion is surrounded by animals. To the right and up a bit is an enraged bull, Taurus, one eye of which is the star Aldebaran (Alpha Tauri). Orion is not afraid of the bull and holds high in his hand a cudgel. He is also guarded by two true dogs: Canis Major and Canis Minor. Each of these constellations has a star of the first magnitude: Sirius in Canis Major—the most brilliant star in the heavens—and Procyon—a slightly less brilliant luminary in Canis Minor.

Incidentally, Lepus, The Hare, distracts Canis Major, The Greater Dog, as it springs from under the feet of Orion. The principal star in this constellation is Alpha Leporis (Mag. 2.6), which forms one of the vertices of a nearly equilateral triangle, the other two being Rigel and Kappa Orionis.

This whole panorama of celestial hunting was drawn on the sky millenia ago, and the above-mentioned group of

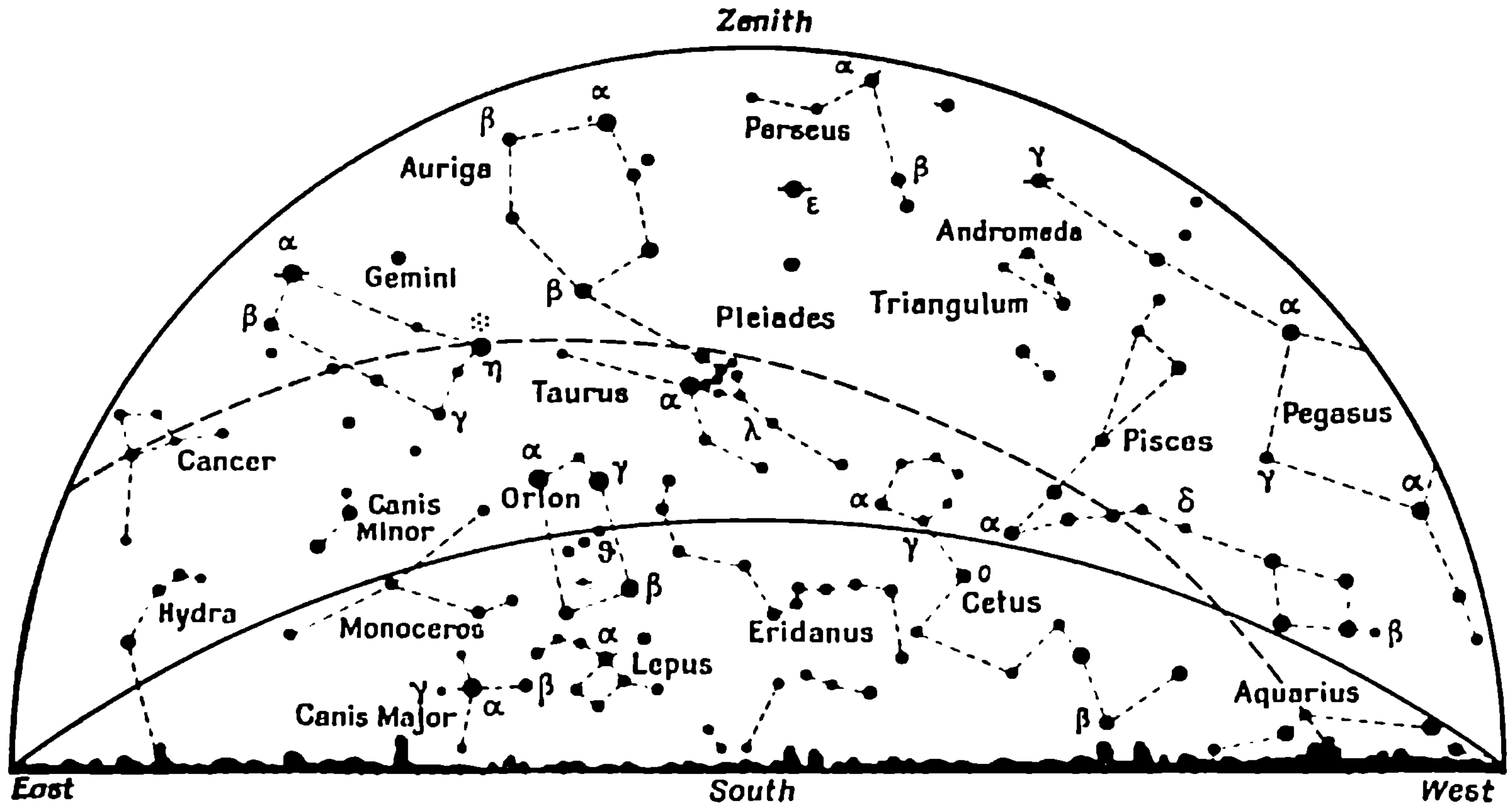


Fig. 40. Southern part of winter sky.

constellations is of the same venerable age as, for instance, The Great Bear, Ursa Major.

Just as ancient are two other bright winter constellations: Gemini (The Twins) and Auriga (The Charioteer). The stars Alpha and Beta Geminorum (these are easy to find just left of Orion) were called Castor and Pollux, after the mythological twins whose father was the mighty Zeus and whose mother was the light-minded earth beauty Leda.

Near the zenith we see a very bright yellowish star Capella, the chief star of the constellation Auriga. The word Capella means "she-goat". Old star maps depicted a small goat carried on the shoulders of the giant Auriga. According to ancient Greek legends, the constellation Auriga immortalizes the Athenian King Erichton who invented the chariot. And the goat on his shoulders is the mythical she-goat Amalthea that was supposed to have suckled the great Zeus.

Of the winter constellations, only two do not have any bright stars. To the right of Orion is the constellation Eridanus, depicting a mythical river in which Phaethon, the unfortunate son of Helios (the sun god) was drowned. He was punished for disobeying his father. This "river" continues far below the horizon and ends in the southern hemisphere of the night sky with the bright star Achernar.

To the left of Orion is the only "young" winter con-

stellation, Monoceros, The Unicorn. It made its appearance on star maps after the invention of the telescope, in 1624, and depicts a mythical animal, the unicorn—a cross between a horse and rhinoceros—that figured frequently in medieval stories.

Except Eridanus and Monoceros, all the other winter constellations may be found without any difficulty because of their brilliant stars.

ORION, The Hunter

There is no other constellation in the skies with so many exciting sights and easily observable objects as Orion. First of all, let us get acquainted with the principal stars.

Rigel, Beta Orionis, is the brightest star in the constellation. It is a bluish-white star with a surface temperature of about 13,000°. It has an apparent magnitude of 0.3 and yet it is hard to believe that this star emits 23,000 times more light than does our sun. Rigel's great luminosity is due to the fact that it is very hot and also very large. Its diameter is 33 times that of the sun! Rigel is justly a supergiant.

Rigel is a triple star. The large school refractor reveals a hot white seventh-magnitude companion at a distance of 9″. The spectrum of the companion star reveals a close-lying pair of stars circling about a common centre of gravity just about every 10 days. Rigel and its companions are very far away from us, 200 parsecs distant.

Great though Rigel is, the red star Betelgeuse (Alpha Orionis) is incomparably greater. This is indeed a titan, and unlike most other stars it has a perceivable disc. At any rate, its diameter has been repeatedly measured with an interferometer and has been found to be 450 times that of our sun! If Betelgeuse took the place of the sun, it would swallow up all the planets out to and including Mars. Just as tragic would it be to substitute Rigel for our sun. This raging hot bluish-white supergiant would burn to ashes the whole organic kingdom of the earth.

Betelgeuse is a semiregular variable star with a fanciful light curve that exhibits two oscillations: with periods of 180 and 2,070 days. It is interesting to note that there is good agreement between the fluctuations of brightness and changes in the diameter of Betelgeuse as determined by in-

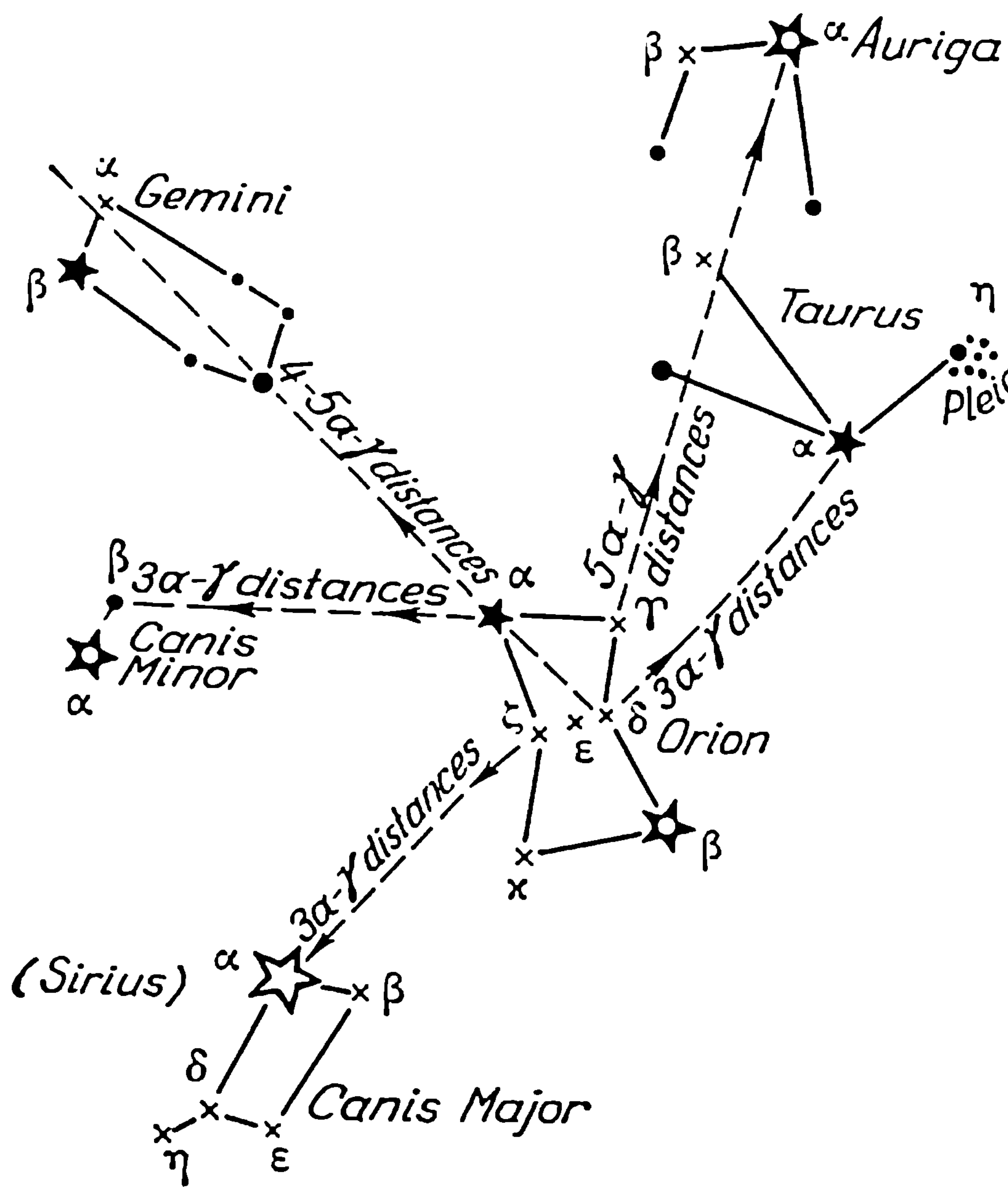


Fig. 41.

terferometer. At maximum brightness the diameter of the star is a minimum (and the temperature is highest), at minimum, just the reverse. This means that fluctuations of brightness in Betelgeuse and similar stars are due to semiregular pulsations.

The star Bellatrix, Gamma Orionis, falls short of Rigel and Betelgeuse in brightness. But it is also a hot giant, even hotter than Rigel, for Bellatrix has a surface temperature of over 20,000°. The name Bellatrix means "female warrior". Medieval books on astrology state that "women born under this star are happy and loquacious".

The fourth star (Kappa Orionis) has no proper name. It too is a hot giant and has a surface temperature of about 25,000°.

The three stars that make up the belt of the celestial hunter are extremely interesting. Zeta and Delta Orionis belong to the rare spectral class O and have surface temperatures in excess of 25,000°. The third star, Epsilon Orionis, is physically very much like Kappa Orionis.

There are two more O class stars in Orion that we have to locate, Sigma and Lambda. Lambda Orionis is the hottest of all the bright stars of this constellation (with a surface temperature in the vicinity of 30,000°).

Under Orion's belt, where modern star maps indicate the stars Theta and Iota and where the old maps show the sword of the celestial hunter, the unaided eye will distinguish a tiny blur, a luminous patch. This is the famous Orion Nebula, whose photographs are just as popular as those of the Andromeda Nebula.

It is strange that apparently neither the ancient nor medieval astronomers knew anything about this nebula. And particularly amazing is the fact that Galileo missed the Orion Nebula as well, though he studied this remarkable constellation with his telescope with great care. It was first detected in 1618 by the astronomer Ziesatus, and even then by accident, when observing a bright comet. Be that as it may, but since then the Orion Nebula has been one of those objects that astronomers never lose interest in.

In binoculars the nebula appears as a hazy luminous smear of irregular outline. Photographs clearly reveal a complex structure and the impressive size of the nebula (Fig. 42). The facts suggest that the Orion Nebula "envelops" nearly the entire constellation, but the naked eye (as in the case of the Andromeda Nebula) sees only the densest and brightest central portion.

These two brightest nebulae—in Andromeda and Orion—are totally different objects. The Andromeda Nebula is a colossal and very distant stellar system made up of tens of thousands of millions of suns. The Orion Nebula is much smaller (with a mean diameter of close to 5 parsecs) and is a cloud of extremely tenuous gases (mainly hydrogen). The Andromeda Nebula is a neighbouring galaxy. The Orion Nebula lies within our own Galaxy and is 350 parsecs from the sun.

The mean density of this gaseous, or diffuse, nebula (to distinguish it from the planetary nebulae) is 10^{17} times less than air density at sea level. In other words, one milligram of this matter occupies a volume of 100 cubic kilometres! The best vacuums attained in our laboratories are millions of times denser than the Orion Nebula!

And still the total mass of this immense structure, which more than comets deserves the appellation of "visible

Fig. 42. The Orion Nebula.

nothing", is stupendous. The matter of the Orion Nebula could go to make about one thousand of our suns or over three hundred million planets the size of the earth.

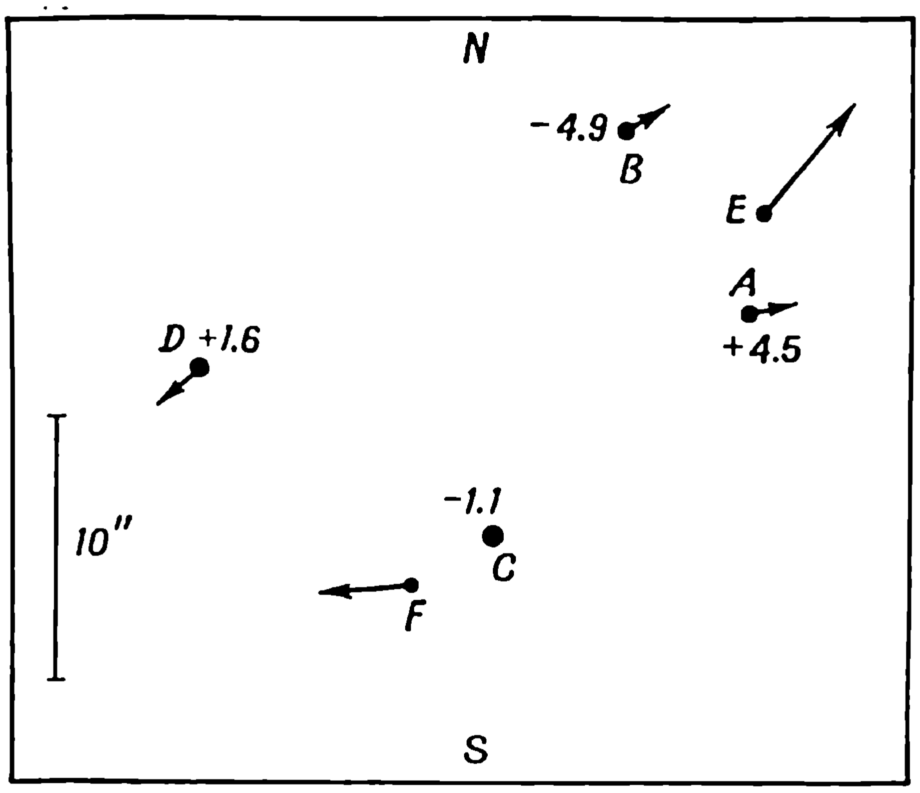


Fig. 43. Star motions in the Trapezium in Orion (numbers indicate absolute magnitude).

That is how the "astronomical" scale of the Orion Nebula makes it very weighty even with an almost negligible mean density. To make the comparison more pictorial: if the earth were reduced to the size of a pinhead, the Orion Nebula on this scale would occupy a volume the size of the earth.

The Orion Nebula shines brightly. But this is cold light due mainly to processes of luminescence excited by hot stars nearby or even embedded within it.

When examining the Orion Nebula, you will probably notice a star, Theta Orionis. Properly speaking, this is not one star but a whole system of six! Four of the brighter ones, which appear to mark the vertices of an imaginary trapezium, are clearly visible in small telescopes (Fig. 43). The fifth and sixth stars of this marvellous system were discovered only in 1826 and 1830 because they are so faint (about Mag. 11) and because they are about 4″ away from the other stars. The remarkable thing about these six stars is that they are hot giants like the ones we have already discussed.

Could this multitude of hot giants in one small region of space—the constellation of Orion—be accidental? Definitely not. This is a typical stellar O association and its nucleus is the sextuple star Theta Orionis.

Hot giants are typical spendthrifts. Rigel, for instance,

converts about 80,000 million tons of its matter into radiation every second! At this rate, Rigel would go bankrupt in 10 million years. But Rigel's brilliance indicates that there is much time ahead, hence it is not yet 10,000,000 years old.

By human standards, 10,000,000 years is quite some time. But on the scale of evolution on the earth this isn't very much at all. The dinosaurs became extinct tens of millions of years ago and so they never saw Rigel. Astronomically speaking, this is a veritable infant!

The other hot giants of the Orion O association (one of the closest to us at a distance of 380 parsecs) are just as young.

The youthfulness of this association also follows from quite a different consideration. Academician Ambartsumyan believes that in the Trapezium of Orion (and other similar multiple systems), the motions of the components cannot be periodical, which is to say that they cannot occur in closed unchanging orbits. Systems of the trapezium type have to break up, and they have to do so in an astronomically brief span of time. Ambartsumyan has estimated that the sextuple Trapezium of Orion is only a few million years old. Which again supports the view that the O association in Orion developed quite recently out of some kind of pre-stellar matter.

The Orion Nebula has a multitude of peculiar types of variables called T Tauri stars after their type star. As a rule, these are not hot giants, quite the reverse, they are cool yellow, orange, and red dwarfs with prominent emission lines in the spectrum. They vary haphazardly in brightness, and there is evidence that the oscillations are due to frequent though nonperiodic ejections of hot luminous gases from the interior into the atmosphere of the star. Generally speaking, type T Tauri stars physically give the impression of erratic, so-called nonstationary stars. This fact alone is an indication of their relative young age.

Actually that *is* the case. T Tauri stars have been proved beyond a doubt to form T associations of their own and to have ages of only several million years.

The Orion constellation contains three T associations, of which the richest (with 220 stars) is concentrated in the region of the star T Orionis not far from the very brightest part of the Orion Nebula.

The constellation Orion is like a boiling "celestial cauldron" where new worlds and stars are being born. The gigantic Orion Nebula and the O and T associations immersed in it create the impression of something young, just born and far removed from any kind of calm equilibrium. This impression is strengthened by two more facts worthy of attention.

The first is that the Orion Nebula and the accompanying young stars are in rotation about a certain axis. This rotation was established by the Soviet stellar researcher P. Parenago. The second fact is the rapid flight of three hot stars from the Orion Nebula: AE Aurigae, 53 Arietis, and Mu Columbae. These stars left the central portion of the Orion constellation about two and a half million years ago and are now racing out in different directions with a velocity exceeding 100 km/s! Apparently, some kind of an outburst threw them from the O association of Orion either at the time of birth or in a period soon afterwards.

The Orion constellation is indeed one of the most restless places in the sky. Quite definitely we are witnessing great cosmic events, which, it is true, develop slowly by human scales.

TAURUS, The Bull

The mythical King Atlas had seven daughters: Alcyone, Taygeta, Merope, Celaeno, Electra, Asterope, and Maia. Under circumstances that are rather obscure (several contradictory versions have come down to us), these sisters were turned into a group of tiny faintly glowing stars that have beautified the constellation Taurus since time immemorial. At any rate the Pleiades (as this star cluster is called) are mentioned in the Bible and by Homer and Hesiod. We are told that at one time all seven Pleiades were of the same brilliance, but that later, Merope was so careless as to be married to a mortal and then her star faded.

Test the keenness of your sight: How many stars do you see clearly in the Pleiades? If it is 6 or 7, you have normal eyesight, if more, then you are sharp-sighted. Persons with exceptional vision can distinguish about ten stars in the Pleiades. But Galileo with his crude telescope was able to count 36 stars in the Pleiades group.

Take a pair of binoculars and enjoy the beauty of this

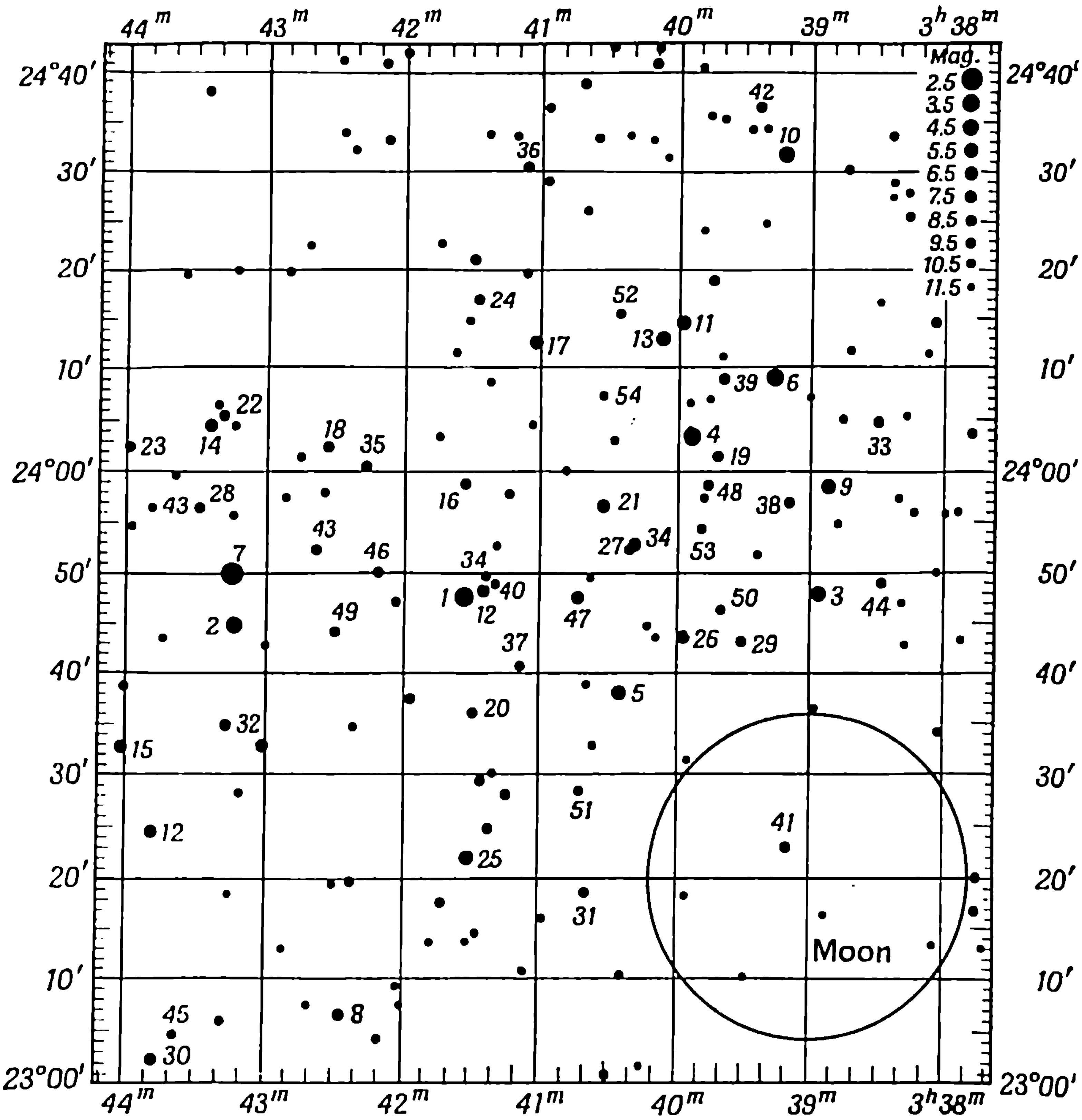


Fig. 44. The Pleiades in a telescope. The circle indicates size of moon's disc.

1—Alcyone; 2—Atlas; 3—Electra; 4—Maia; 5—Merope; 6—Taygeta; 7—Pleione; 9—Celaeno; 10—Asterope

magnificent open star cluster. Check with a map of the Pleiades (the name means "multitude" in Greek) and find the principal stars of the cluster. You will find the parents of these celestial sisters, their father Atlas and their mother Pleione (Fig. 44).

The brightest star of the Pleiades is Alcyone (Eta Tauri) next to which is a triangle of tiny stars, the optical companions of Alcyone. The principal stars of the Pleiades are those that have been given mythical names; they are hot

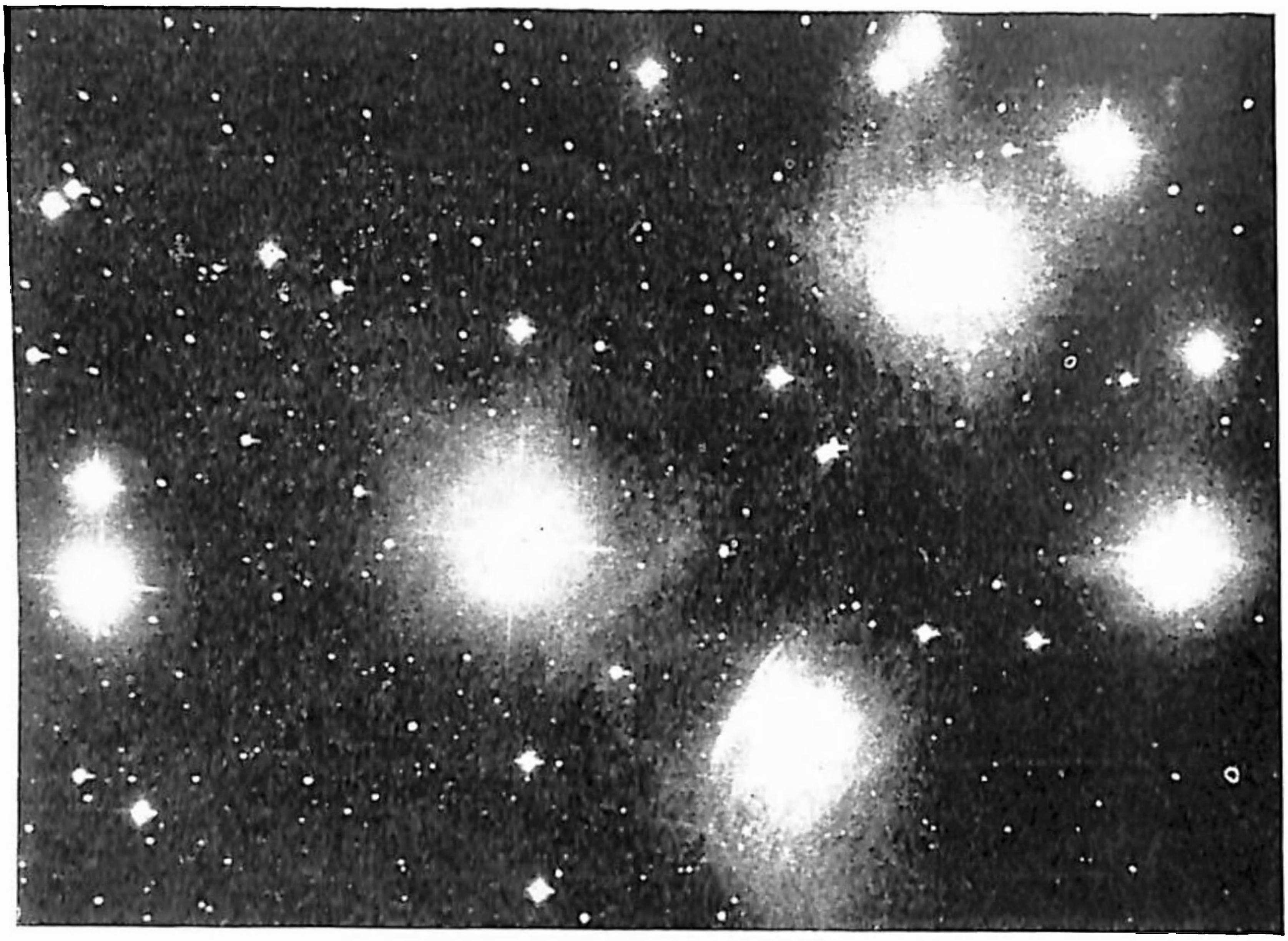
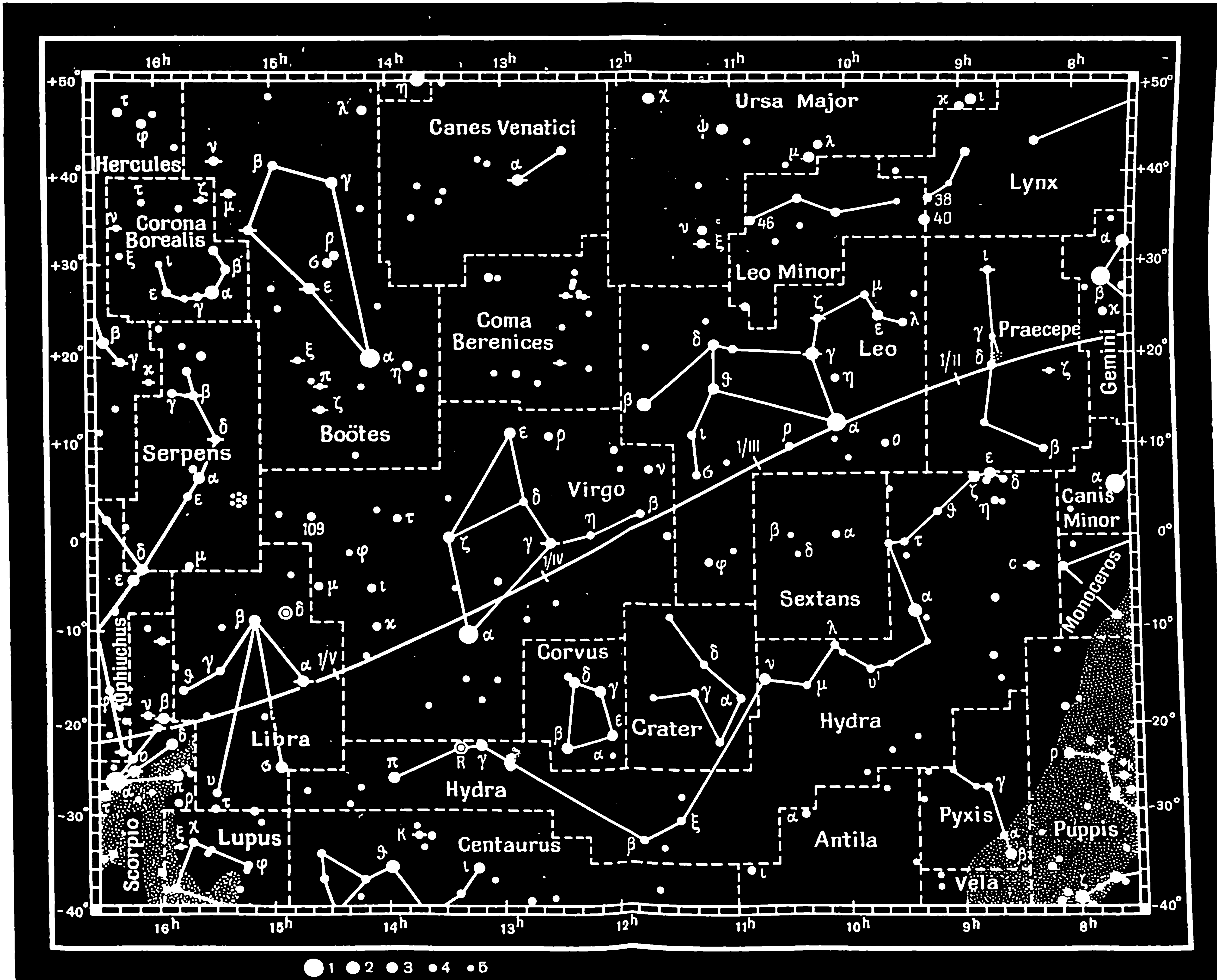


Fig. 45. The nebula associated with the Pleiades.

white giants with surface temperatures not less than 15,000°. Alongside them, our sun would appear a feeble star of the tenth magnitude. But among the tens of stars that make up this cluster, there are cooler stars than Alcyone and there are some whose physical characteristics are very much like those of our sun. This is an asterism of highly diversified stars, not of all types though (there are no red giants, for instance).

The Pleiades are one of the closest open star clusters being at a distance of only 130 parsecs from the earth. That is what makes them look so effective even to the naked eye. In the sky they occupy an area several times that of the full moon (this is hard to believe, isn't it?) and in space are spread out in all directions to 22 light years. As in other open star clusters, the stars of the Pleiades are flying off in space along almost parallel routes and with just about the same velocities.

The Pleiades are a much more compact group than any other O association, but they are very young too. Repeated



Ursa Major
Canes Venatici
Hercules
Corona Borealis
Lynx
Leo Minor
Coma Berenices
Leo
Praecepe
Gemini
Boötes
Serpens
Virgo
Canis Minor
Sextans
Monoceros
Corvus
Crater
Ophiuchus
Libra
Hydra
Pyxis
Puppis
Scorpio
Lupus
Centaurus
Antila
Vela
16h 15h 14h 13h 12h 11h 10h 9h 8h
+50° +40° +30° +20° +10° 0° -10° -20° -30° -40°
1 2 3 4 5

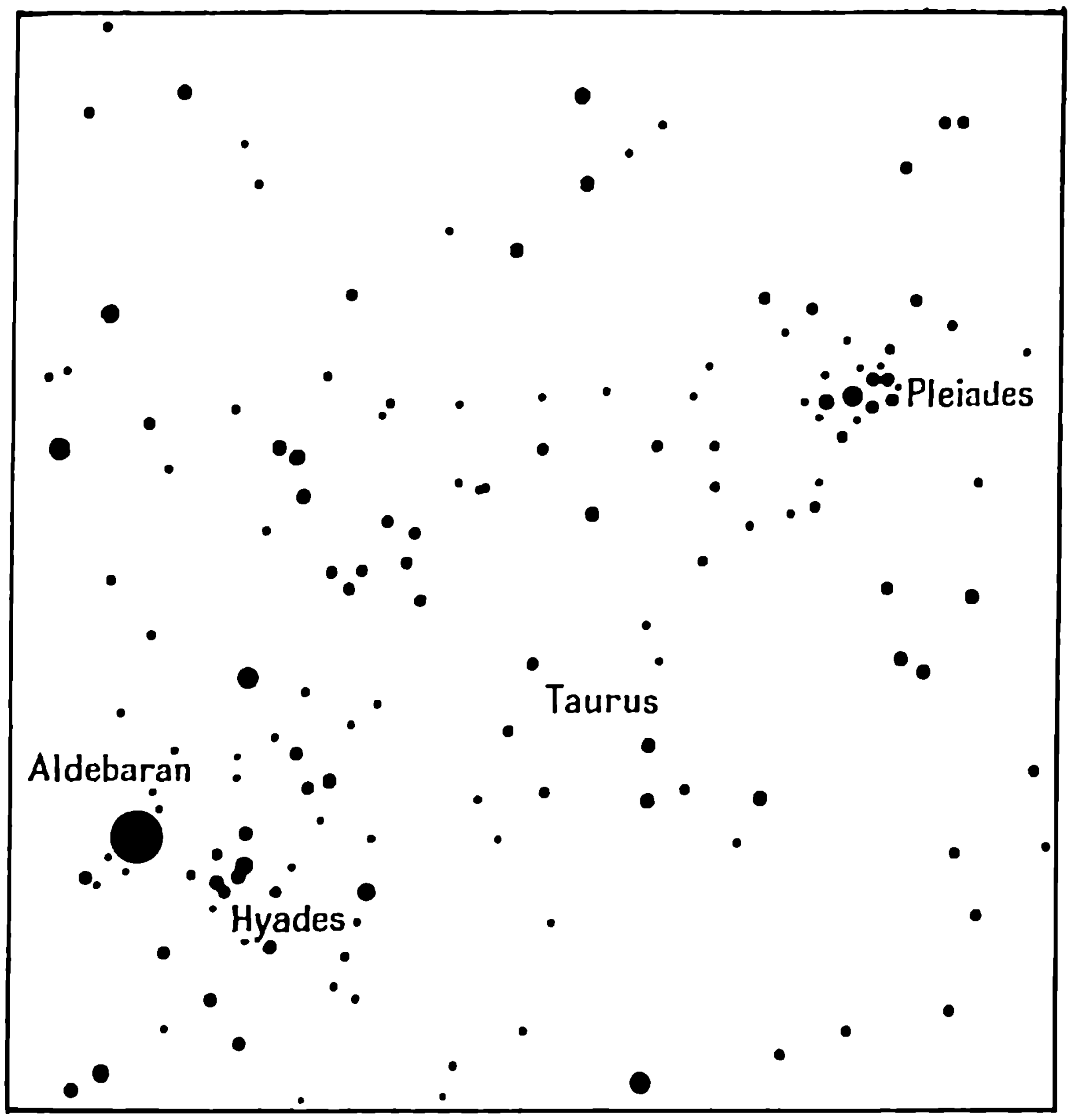


Fig. 46. The Hyades and Pleiades.

attempts have been made to figure out their age. According to estimates published in 1953, 280 of the Pleiades stars were born 2.5 million years ago at the earliest. If that is so, then the age of the Pleiades is of the same order of magnitude as that of humanity here on earth!

A tenuous transparent nebula, in the form of a haze in which the Pleiades are immersed, was discovered way back in 1859 (Fig. 45). Unlike the Orion Nebula, this is not a self-luminous nebula. It simply reflects the light of the Pleiades stars within it and consists mainly of solid minute particles of cosmic dust.

The principal star of Taurus is yellowish-orange Aldebaran. It is situated (in the sky but not in space) in the very midst of an open star cluster, the Hyades (Fig. 46). This asterism consists of approximately two hundred stars surrounding Aldebaran. Their proper motions are in the direction of a single point in the sky, the so-called vertex, close to Betel-

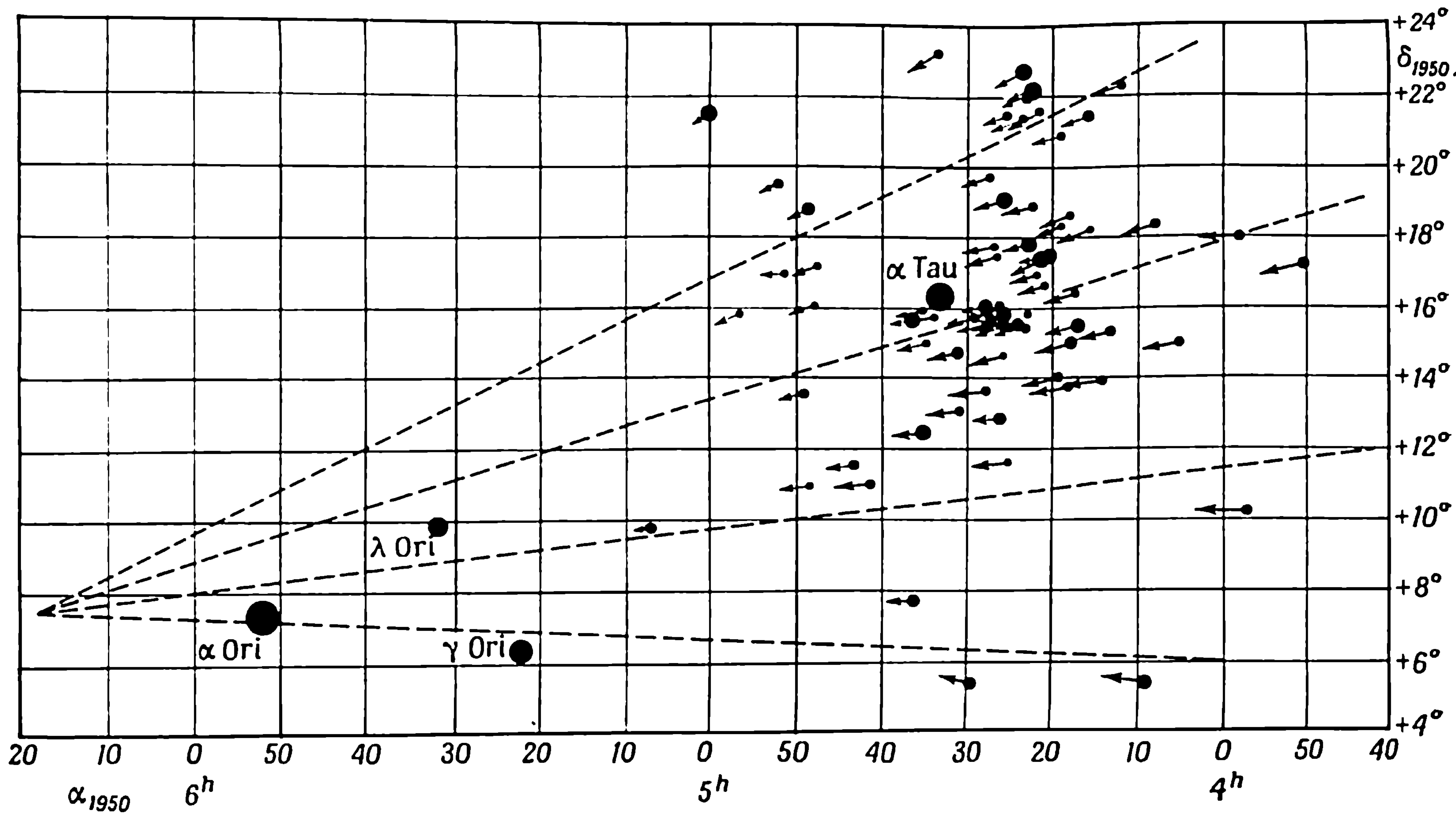


Fig. 47. The Hyades and their proper motion.

geuse (Fig. 47). In the Hyades the motions proper of the stars are very considerable and it is easy to locate the vertex, which is not very definite in the case of the Pleiades. For this reason, clusters such as these—they are perceptibly in translation—are called *moving clusters.*

Of course, all the Hyades stars are moving parallel in space and the apparent convergence of their paths in a vertex is due to perspective, like the receding tracks of a railway.

In make up, the Hyades are probably no less diversified than the Pleiades. But on the whole, the Hyades are cooler and smaller than the Pleiades. There are a good many stars like the sun here and even several red giants. The Hyades have no enveloping nebula like the Pleiades, which is another indication of considerable age. Judging from a range of information, the Hyades are about one thousand million years old.

The Hyades are the closest star cluster, a mere 40 parsecs distant. It is nearly spherical and has a mean diameter of close to 33 light years. It has been calculated that about 80,000 years ago the Hyades passed by our sun at their closest, which was half the present distance. In 65 million years the Hyades will have receded so far that they will occupy an area less than full moon, and the brightest stars now perfectly visible to the naked eye will become faint objects of the twelfth magnitude. So you see, celestial pictures are changeable too, but so is everything else in this world.

As we have already pointed out, Aldebaran does not belong to the Hyades. This cool orange giant is nearly 30 times the diameter of the sun and is distant 21 parsecs.

The Taurus constellation contains yet another extraordinary sight, the famous Crab Nebula (Fig. 48). It lies near a bright star, Zeta Tauri, but this is a difficult object to locate. Only on very dark transparent nights is it visible in a telescope or strong binoculars as a minute luminous oval patch about 6′ by 4′ in size.

When in 1758 Messier was searching this part of the sky for a comet, he nearly confused it with the then unknown Crab Nebula. It was precisely this irritating circumstance that pushed him to compile his now famous catalogue of nebulae, in which the Crab Nebula is recorded as number one.

"Interference No. 1" has of late attracted much attention.

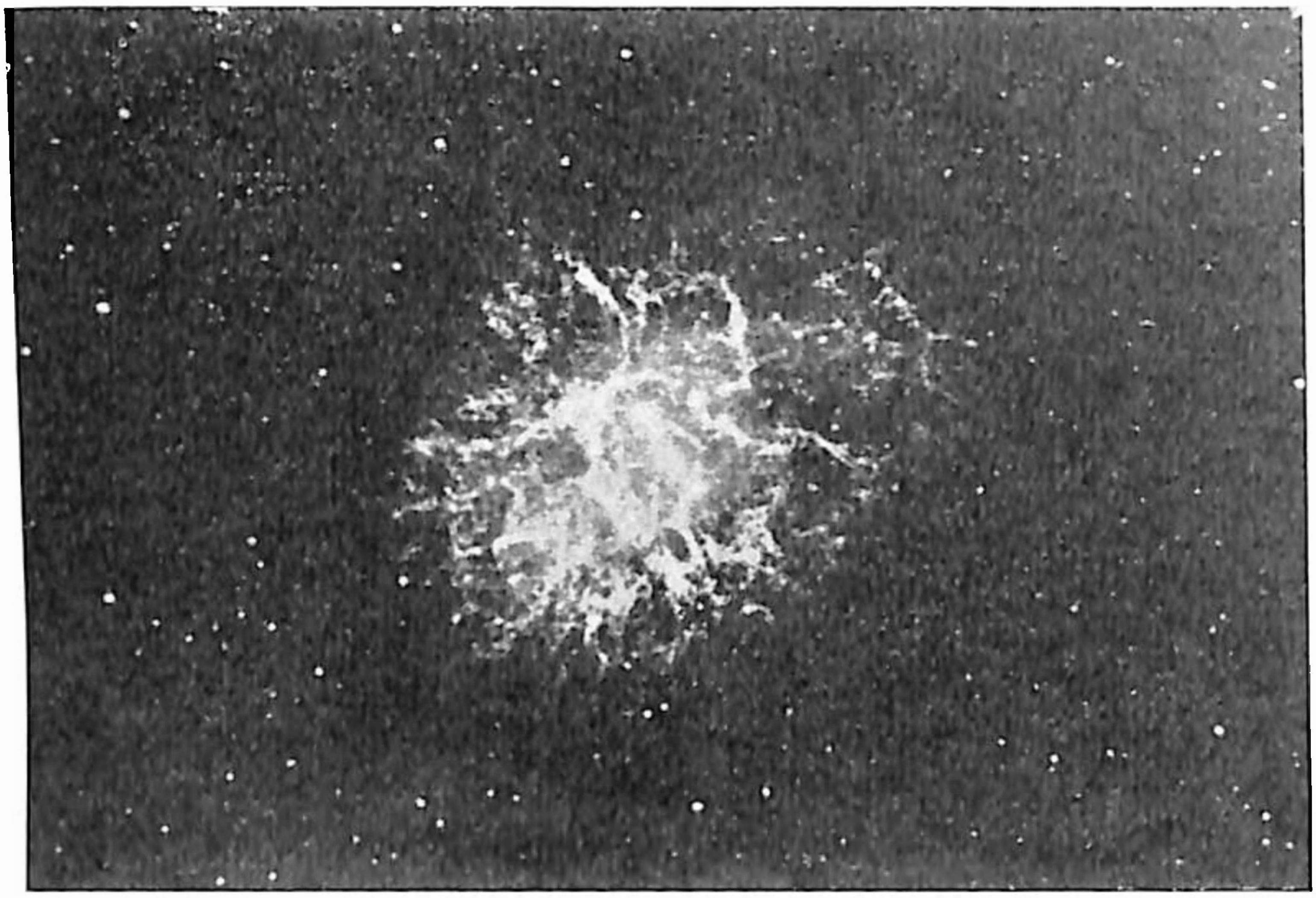


Fig. 48. The Crab Nebula.

This is one of the most powerful sources of cosmic radio emission. In the catalogues of radio astronomers it is designated as Taurus A. Good photographs of the nebula show it to be crab-like in appearance: filaments of the nebula resemble antennae and limbs.

It was here that in 1054 a supernova burst forth. What is left now is a small extremely hot star of ninth magnitude with a very unusual spectrum. A remarkable thing about the Crab Nebula is that the gases which go to make it up are flying out in all directions from this star with a velocity of about 1,000 km/s. Even photographs taken at 20- to 30-year intervals reveal the Crab Nebula as expanding.

Can there be any doubt that what we see here is the former supernova and the gases that shot out in a stupendous explosion. Incidentally, the strange star in the centre of the nebula has a temperature (judging by the spectrum) of at least 150,000°, which is quite impossible for ordinary stars.

Nebulae which intensively emit radio waves are known as radio nebulae. The constellation Taurus certainly has

the most remarkable radio nebula, the nature of which has not yet been fully deciphered.

In comparison with this celestial rarity, other interesting objects of the Taurus constellation, like the optical double stars Theta, Sigma, Kappa or the eclipsing binary Lambda (with amplitude from Mag. 3.5 to 4.0 and with a period of 3.95 days) deserve only brief mention.

CANIS MAJOR, The Greater Dog

The Dog Days—or canicular days—of hot summer. The name comes from the principal star of the constellation Canis Major, Sirius, which is the brightest star in the whole sky and in Greek means "brilliant".

At one time in ancient Egypt, during the days close to the summer solstice, Sirius appeared for the first time in the rays of the rising sun. This time of year was determined with exactitude by the Egyptian priests because soon afterwards the Nile River overflowed.

Sirius, chief star of Canis Major, was for a long time called the Dog Star. But in Latin, dog is "canis", hence the phrase canicular days for the sultry summer period. This was thought to be a time of unrest and there was a belief that dogs went mad during this period and that maladies prevailed.

Today, we no longer look at Sirius with fear, but with wonderment. This is truly a magnificent jewel of the skies, and despite the scintillating rainbow of colour, the star is a pronounced blue.

Sirius is the brightest star of all. It has a magnitude of —1.4. Canopus is the only other star with a negative magnitude.

Sirius is one of the closest stars too, seventh in order of distance from the sun. A spaceship hurtling away at 10 km/s would reach Sirius in 300,000 years. Light covers this distance in 9 years. Sirius is roughly twice as large across and twice as heavy and twice as hot as the sun. But its luminosity is 24 times that of the sun and to replace our sun with Sirius would make it unbearably hot on the earth, so hot, in fact, that the oceans would probably boil away.

Sirius has a very substantial proper motion: 1″.3 per year. Line displacement in its spectrum indicates that the distance between the sun and this brightest of stars is increasing at the rate of 8 km/s.

In his study of the flight of Sirius in space, the famous German astronomer and mathematician Bessel pointed out, as far back as 1844, that the trajectory of this star when projected on the celestial sphere depicts a strange type of wave-like curve. Bessel attributed this wobbling of Sirius to the perturbing action of an invisible companion star circling together with the primary (Sirius) about a common centre of gravity with a period of 50 years.

Bessel's theoretical prediction was later brilliantly confirmed. In January of 1862, the noted American optician Alvan Clark was testing a new 18-inch refractor and discovered next to Sirius a tiny star which subsequently exhibited the orbital motion so accurately predicted by Bessel's calculations. This was a triumph of "gravitational astronomy" in no way inferior to the historic discovery of Neptune.

Sirius' companion star is a white star of Mag. 8.6. At its largest separation from Sirius (about 11″) it is readily picked up even by small telescopes, but as it approaches Sirius, observations become progressively more difficult.

Sirius' companion is sometimes called the "Puppy Star" and was the first *white dwarf* to be discovered. We now know denser stars than this, but at the time of discovery its physical properties appeared to be utterly unbelievable. The Puppy has nearly the same mass as the sun, but its diameter is only three times that of the earth. This brings up its mean density so high that a matchbox full of such matter would weigh a ton! Today we are inclined to view such stars as bankrupt in the sense that they have used up their whole supply of hydrogen fuel and remain luminous solely due to a very slow process of contraction. The state of matter in this companion star and in other white dwarfs may be described as a degenerate gas. To astrophysicists, this term means a mixture of ionized atoms and free electrons under tremendous pressure. Though such plasma is denser than steel, it is a gas because it possesses the elasticity peculiar to gases. Studies of the companion of Sirius have demonstrated that matter in stellar interiors can exist in unusual states and all this greatly enriches atomic physics. Sirius' companion was the body that suggested for stars the name "celestial laboratories".

Below Sirius it is easy to find, especially with binoculars, the star o^2. This is a typical representative (type star) of

a very rare class, the so-called Wolf-Rayet stars. The broad emission lines in their spectra indicate that these stars are losing gas at a tremendous rate with velocities of several thousands of kilometres a second. Their atmospheres are extremely extended, and the rapidity of the processes leaves no doubt that a star in this state cannot last for more than a hundred thousand years. Now this means that the star o^2 Canis Majoris is one of the youngest stars observable in the sky.

Midway between Sirius and o^2 is a bright open star cluster M41. It is comparatively poor in stars but looks rather impressive in a small telescope. This swarm of stars, 7.4 parsecs across, is nearly 50 times farther away than Sirius.

In the constellation Canis Major is a unique pair of stars designated by the letters UW. It is an eclipsing variable with an amplitude of 4.5 to 4.8 stellar magnitude and a period of 4.4 days. Both components of the system are extremely rare supergiants of the spectral class O8. Judging by the light curve, they are so close together that their mutual gravitational attraction has produced ellipsoidal shapes. We have already encountered a similar case in W Ursae Majoris. But the most unusual thing is the mass of the supergiants of the UW Canis Majoris system. These are the most massive known stars. Each one "weighs" $71{,}500 \times \times 10^{24}$ tons, which is about 30 times that of the sun and nearly 10 million times the mass of the earth!

It is now time to mention Beta Canis Majoris, a star very much like the familiar Beta Cephei (mentioned in the chapter dealing with the Cepheus constellation), this mysterious variable star with slight but regular periodic fluctuations of brightness.

CANIS MINOR, The Lesser Dog

Although the principal star of the constellation Canis Minor—yellowish Procyon—is inferior to Sirius in size, temperature and luminosity, there is much in common between these stars.

They both head small constellations in which not a single other star can compete with them in brightness. Both stars have white dwarf companions, the stories behind the discoveries of which are very much alike.

Along with his studies of the motion of Sirius, Bessel

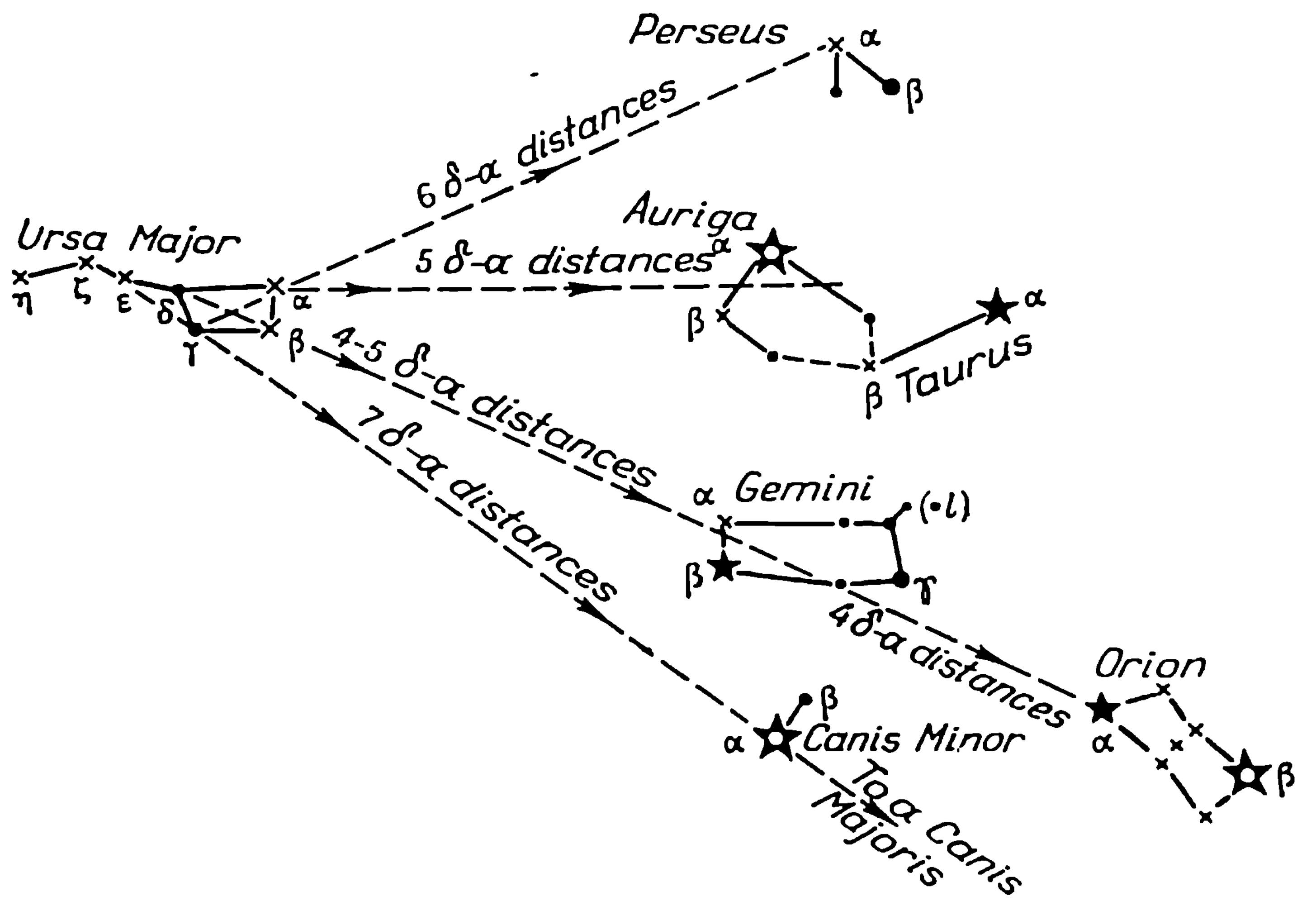


Fig. 49.

noticed similar wave-like deviations in the proper motion of Procyon as well. Here too Bessel suspected the existence of an invisible body perturbing the motion of Procyon.

Curiously, in that same 1862 when Clark saw the companion of Sirius, a German astronomer, Auwers, computed the orbit of the unobserved companion of Procyon. Only 34 years later did Scheberle, at the Lick Observatory, discover the celestial body predicted half a century before. This was the third time such a prediction had come true, repeating the Neptune story. Here is what we know today about Procyon and its companion.

Procyon is a yellowish star of Mag. 0.5 with a luminosity only 5.8 times that of the sun. It is somewhat larger than the sun and a bit hotter, the surface temperature reaching nearly 7,000°. Like Sirius, Procyon is one of our neighbouring stars at a mere distance of 3.5 parsecs. On the whole, there is nothing outstanding about Procyon and if it weren't for its proximity to the earth (and therefore its appreciable brightness), we would probably not pay any attention to it at all.

But the companion star is quite a different matter. It is quite impossible for the amateur astronomer to see this 11th-magnitude star at a mean distance of 4″ from Procyon. It emits 10 times less light than does Sirius' companion

and is even a denser white dwarf than the Puppy Star. But there can be no doubt about the similarity of these two unions of utterly unlike stars (Sirius and Procyon with their dwarf companion stars).

GEMINI, The Twins

Castor and Pollux are the two principal and the two brightest stars of the constellation Gemini. Their names suggest that they should be somewhat alike. Nature, however, disregards myths and endowed these stars with completely different properties. Castor is a multiple star, the two chief components of which are hot blue stars. Pollux is a cool orange single star. Pollux is closer to us than Castor (10 and 14 parsecs, respectively). Actually, Pollux is quite an ordinary star, whereas Castor is one of the most unusual of stars.

In the large school refractor you can easily see that Castor consists of two blue stars of Mag. 2.0 and 2.9 separated by a distance of 4″.1. This was the first double star (binary) in which William Herschel in 1804 detected an obvious orbital motion with a period (recently computed) of 341 years. The two stars are separated by a distance of 76 astronomical units.

At 73″ from this pair of stars, which have the conventional designations Castor A and Castor B, we see a ninth-magnitude star, Castor C. Unlike the first two hot giants, Castor C is a small cool dwarf of reddish hue. The distance between it and the two main stars is at least 960 astronomical units. “At least” because the measured distance is a projection of the true distance on the celestial sphere. During the past century and a half, observations of Castor C have not revealed any signs of orbital motion, which is not surprising since its period about the centre of gravity of the system is at any rate not less than several tens of thousands of years!

When a careful study was made of the spectra of these three stars, it developed that each of them is a spectral binary. Castor A and Castor B form two pairs of twin stars separated by distances of only 10,000,000 kilometres, which is 1/6 the distance between the sun and Mercury! This highly intimate union of four stars must produce ellipsoidal shapes.

Castor C consists of two twin dwarfs separated by 2.7 million kilometres, which is merely twice the size of the sun. The orbits of these stars are such that Castor C is an eclipsing variable star with a period of only 19 hours. The two other more sizable pairs orbit about their common centre of gravity more slowly: 9 days in the Castor A system and 3 days in the Castor B system.

Thus, Castor is a sextuple star like Theta Orionis. Who knows, perhaps there are planets there too, in which case inhabitants witness the spectacle of six suns at once!

After this family of six stars whose origin represents a great mystery to cosmogonists, the binary star Delta Geminorum will seem quite ordinary. Still, let us try to resolve it. The primary star is a yellowish giant of magnitude 3.5, at a distance of 6″.8 is a small red companion of Mag. 8.2.

The Gemini constellation has two bright variable stars. One, Zeta Geminorum is a Cepheid that periodically oscillates in brightness with an amplitude ranging from Mag. 3.9 to 4.3. The period is close to 10 days but fluctuates somewhat. The second variable, Eta Geminorum, is interesting in that it is a spectral binary and an eclipsing variable with a period of 2,984 days and also a semiregular variable with a mean period of 233 days and an amplitude of magnitude from 3.1 to 3.9. Such cases of combinations of different types of variability in one star are not so rare.

Not far from this variable is an open star cluster M35. It occupies about the same area in the sky as the full moon, actually, however, it has a mean diameter of about 7 parsecs. It is 20 times greater than the Hyades and about 800 parsecs distant.

Binoculars show many tiny faintly shining stars studding the area, quite a few of which are hot giants. The more powerful the telescope, the more stars appear in the field of view. According to the noted astronomer of last century, Lassel, this is an extraordinary, amazing celestial object and something that is unforgettable when once seen. This description may be a bit exaggerated but Lassel's enthusiasm was in part perhaps due to the large power of his reflector. Even school-type telescopes reveal the star swarm in Gemini as a very beautiful sight.

AURIGA, The Charioteer

We feel we must warn the reader that the stars which we shall now discuss appear very ordinary in school telescopes. And there is nothing remarkable about them when viewed in the world's largest telescopes either. But still they are unusual. Telescopic observations, however, did not help to bring out any remarkable features; it is the light curve and the character of the spectrum that are so remarkable.

Let us begin with Capella: a brilliant yellow star of Mag. 0.09. This is the principal star of the constellation Auriga. When its physical properties were still poorly studied, some astronomers considered Capella a twin of the sun. Similarities there are, but only in colour and temperature. Otherwise, Capella is quite different from the sun.

Capella, it turns out, consists of two very close-lying yellow giant stars. One of them is 12 times the diameter of the sun and 4.2 times its mass, the other is somewhat smaller and lighter. It is 7 times the solar diameter and 3.3 times as massive. The distance between the centres of these stars is nearly equal to the radius of the earth's orbit. For this reason, we can picture the Capella system if we imagine Capella A (the primary) taking the place of our sun, and Capella B the place of the earth. The first of these stars will outshine the sun 110 times, the second 70 times.

The angular distance between Capella A and Capella B is extremely small, only $0''.05$, which lies at the very limit of the resolving power of the greatest telescopes in the world. But a spectral analysis convincingly demonstrates the double nature of Capella; and it is easy to find the period of revolution of this system of two suns from the periodic shift of spectral lines: it is close to 104 days.

Photoelectric measurements have shown that Beta Aurigae is the second brightest (after Capella) star in this constellation. The difference in magnitude is 0.1, but it varies its brightness with great regularity. An analysis of the spectrum and the light curve has proved sufficient to tell us some interesting things about this eclipsing variable.

Both components are hot blue giants as alike as twins. Their radii are 1.9 million km, they are 2.4 times as massive as the sun. They have absolutely identical densities and luminosities. The distance between their centres comes

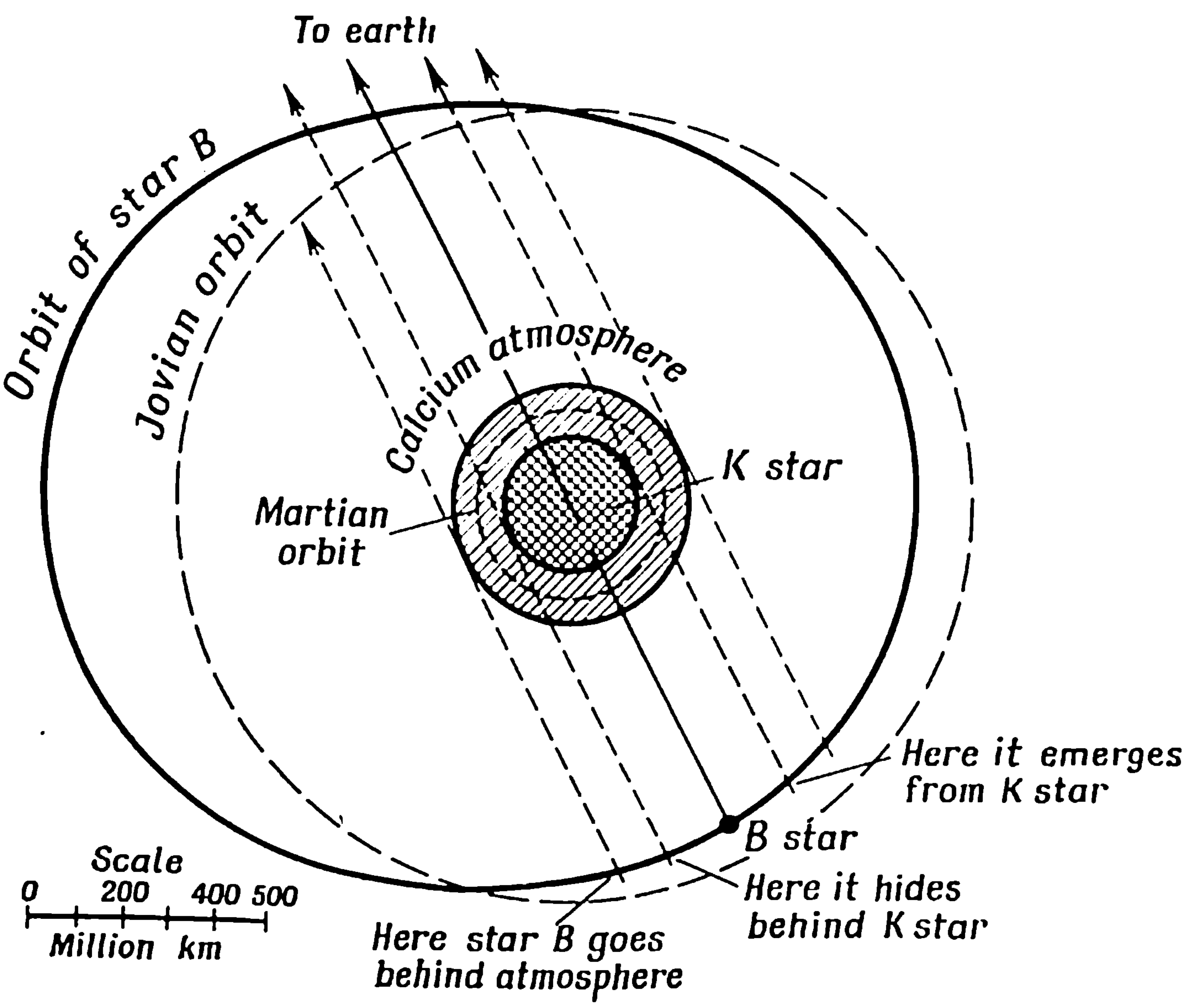


Fig. 50. The star Zeta (ζ) Aurigae.

out to only 12.5 million km, and the period of revolution is 3.96 days.

Diametrically opposite are the two stars that make up the Zeta Aurigae system (Fig. 50). The two stars are quite unlike. One of them is a very hot blue-white star 13 times more massive than our sun and 4 times bigger in diameter. The second component is a reddish-orange cool supergiant 32 times more massive than the sun and 293 times greater in diameter. This star is enormous, so big in fact that if placed at the centre of the solar system it would swallow up Mercury, Venus, the earth and just fall short of Mars.

The blue star has a surface temperature of 15,000°, the red one, 3,160°. But the latter emits 1,900 times more light than the sun and the former only 400 times more light. The blue one revolves about the red star in an orbit that is just about the orbit of Jupiter. By pure accident, the line of sight of the terrestrial observer lies almost in the plane of this orbit, and we can therefore see how one of the stars periodically blots out the other. When the red star eclipses the blue star, the brightness changes but slight-

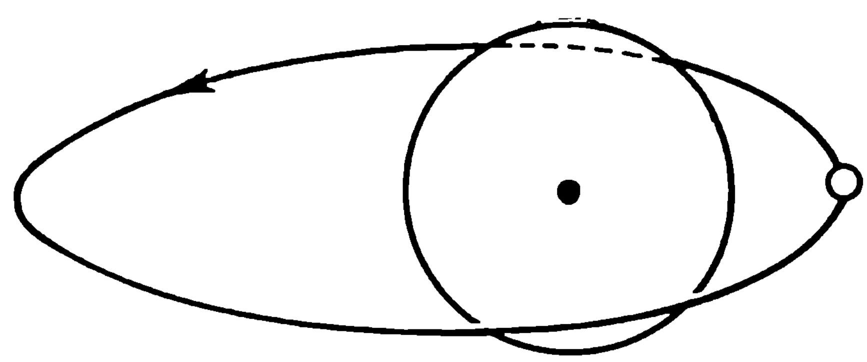


Fig. 51. The system Epsilon (ε) Aurigae.

ly at first, as if a nearly transparent haze were enveloping it. This haze is an enormous atmosphere of the red supergiant. Spectral studies indicate that in it calcium prominences sometimes leap out to 233 million kilometres, which is 1.5 times the earth-sun distance.

The period of the Zeta Aurigae system is 972 days, and full eclipse of the blue star by the red star lasts nearly 40 days.

Stupendous as the scale of these phenomena may seem, they fall far short of what was discovered in the eclipsing variable system of Epsilon Aurigae. Nature surely did not skimp on wonders to startle the human imagination.

It is already interesting to learn that Epsilon Aurigae is an eclipsing variable with the largest known period of variation of brightness: 27 years. The amplitude of variation is 0.75, which means that at maximum Epsilon Aurigae is twice as bright as at minimum.

A detailed analysis of the spectrum and light curve of Epsilon Aurigae carried out in 1937 by the prominent American astrophysicists D. Kuiper, O. Struve, and B. Strömgren led to surprising conclusions.

The Epsilon Aurigae system consists of two stars, a visible one and an invisible one. The one we see in the constellation Auriga as a yellowish star with a mean magnitude of 4 is an enormous supergiant with a surface temperature of 6,300°. This star is 36 times more massive than the sun and 190 times greater in diameter. But these dimensions are nothing compared with those of the second star, which is the largest of any that we know. It has a diameter 2,700 times that of the sun. It could easily accommodate all the planets of the solar system in their orbits out to Saturn inclusive. Fig. 51 shows the Epsilon Aurigae system to a relative scale.

Despite its horrific size, the second component's luminosity is small and just about equal to solar luminosity. The greatest of all stars has an apparent magnitude of close to 16; it is separated from its neighbour by an angular distance of 0″.03. Considering the great difference in the apparent brilliance of the components, we may be sure that it is still impossible to resolve the pair optically.

Why is it that with such immense dimensions Epsilon A has such a low luminosity? The secret lies in the fact that Epsilon is a very cool star (1,350° at the surface) and it emits mostly invisible infrared rays. Also, the mean density is so small that Epsilon A is transparent: that is why no changes occur in the spectrum when the companion is eclipsed by the primary. But then why does the brightness of Epsilon B fluctuate?

American astronomers are of the opinion that Epsilon B, which radiates 10,000 times more light than the sun, ionizes the closest-lying outermost layers of the infrared star Epsilon A. The result is an "ionization spot" which moves over the surface layers of the atmosphere of Epsilon A as Epsilon B moves. When A is behind B and the ionization spot blots it out from the terrestrial observer, Epsilon B becomes fainter because ionization gases are less transparent than nonionized gases. This ingenious explanation fully accounts for all observational events.

That is how much information may be extracted from an analysis of light rays, which are the basic link connecting us with the stars.

The constellation Auriga is rich not only in extraordinary eclipsing variable stars, but in open star clusters too. Using binoculars or telescope, locate three clusters, M36, M37, and M38, which actually form a triple cluster. (Look for them between Theta Aurigae and Beta Tauri.) In the main they consist of hot white stars of spectral class B with a slight admixture of cooler stars like the sun. Together, the three clusters contain about 350 stars, the brightest and richest being M37. Like M36, it is at a distance of 1,100 parsecs, whereas M38 is closer: 850 parsecs. Their true diameters lie somewhere between 6 and 11 parsecs.

The investigations of Soviet astronomers suggest that the entire assemblage of open star clusters form a plane subsystem in our Galaxy.

MONOCEROS, The Unicorn

In this extensive constellation poor in bright stars (only one is brighter than fourth magnitude), there is only one sight to see, the marvellous diffuse nebula known to astronomers as the Socket-Shaped Nebula (Fig. 52). Good photographs do seem to resemble a socket (disc-shaped); it might even be classed as a planetary nebula.

But, we repeat, this is a diffuse nebula lighted up from

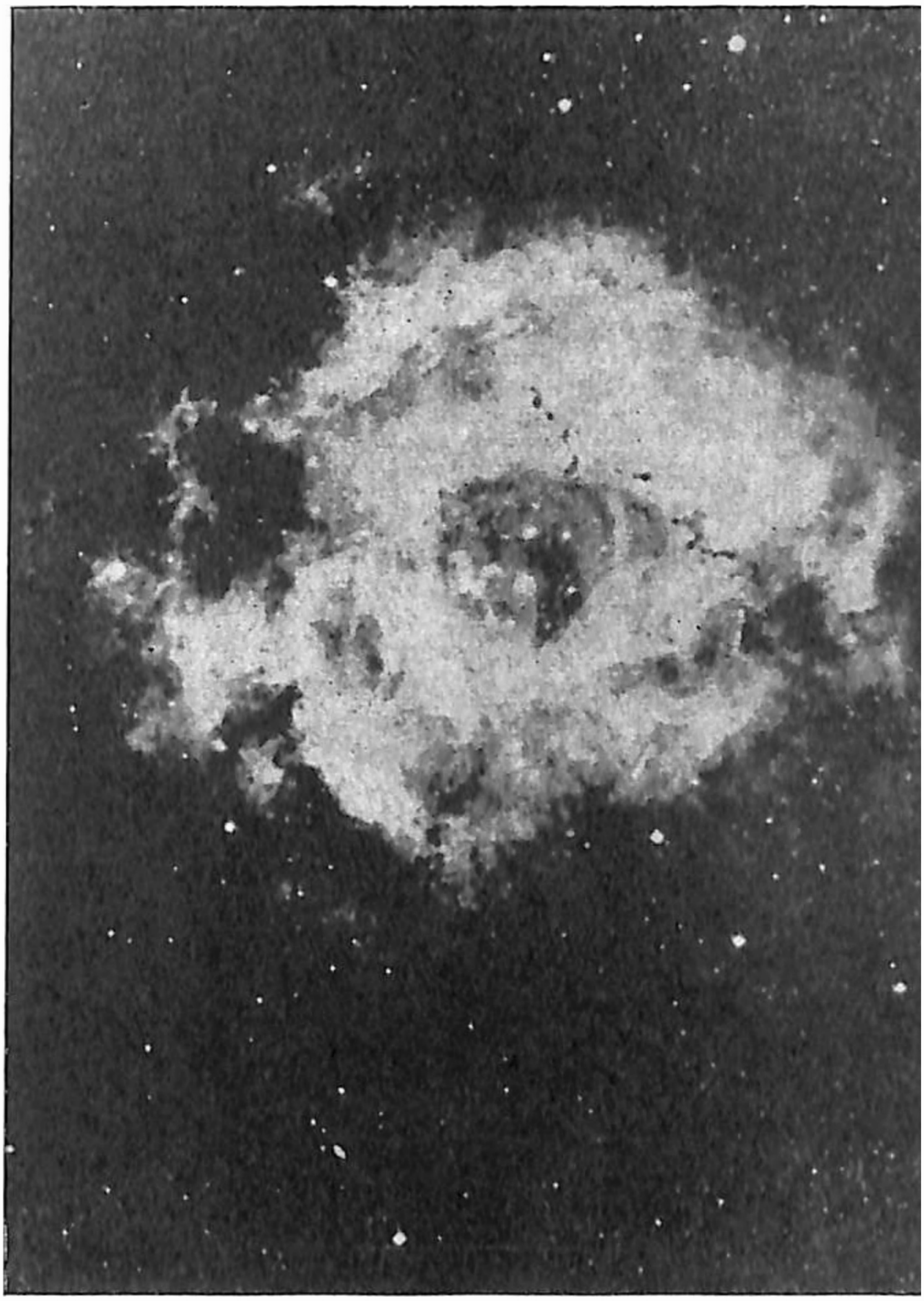


Fig. 52. The Socket-Shaped Nebula.

inside by very hot O class stars. It has an apparent diameter twice that of the moon, and it is 1,100 parsecs distant from us.

ERIDANUS, The Celestial River

In the constellation Eridanus you will find a triple star o^2. The primary is of Mag. 4.6, and at a distance exceeding a minute of arc it has a companion of Mag. 9.7, which in turn is a binary (third component is of Mag. 11.2).

The primary star is similar to our sun, but somewhat smaller and cooler. The second star is a very cool red dwarf roughly one-fifth the volume and mass of the sun. The third star is a white dwarf 50 times smaller than the sun, but with a density exceeding the solar density 64,000 times. The white and red dwarfs are whirling about with a period of 250 years and together circle the primary in an enormous orbit with a period that has not yet been reliably determined. This stellar triple is a neighbour, only 5 parsecs away.

The star Epsilon Eridani (Mag. 4.2) is remarkable for the fact that it is one of two stars of the northern hemisphere that may have inhabitable planets. At any rate, like Tau Ceti, this star is in the centre of attention. It is under

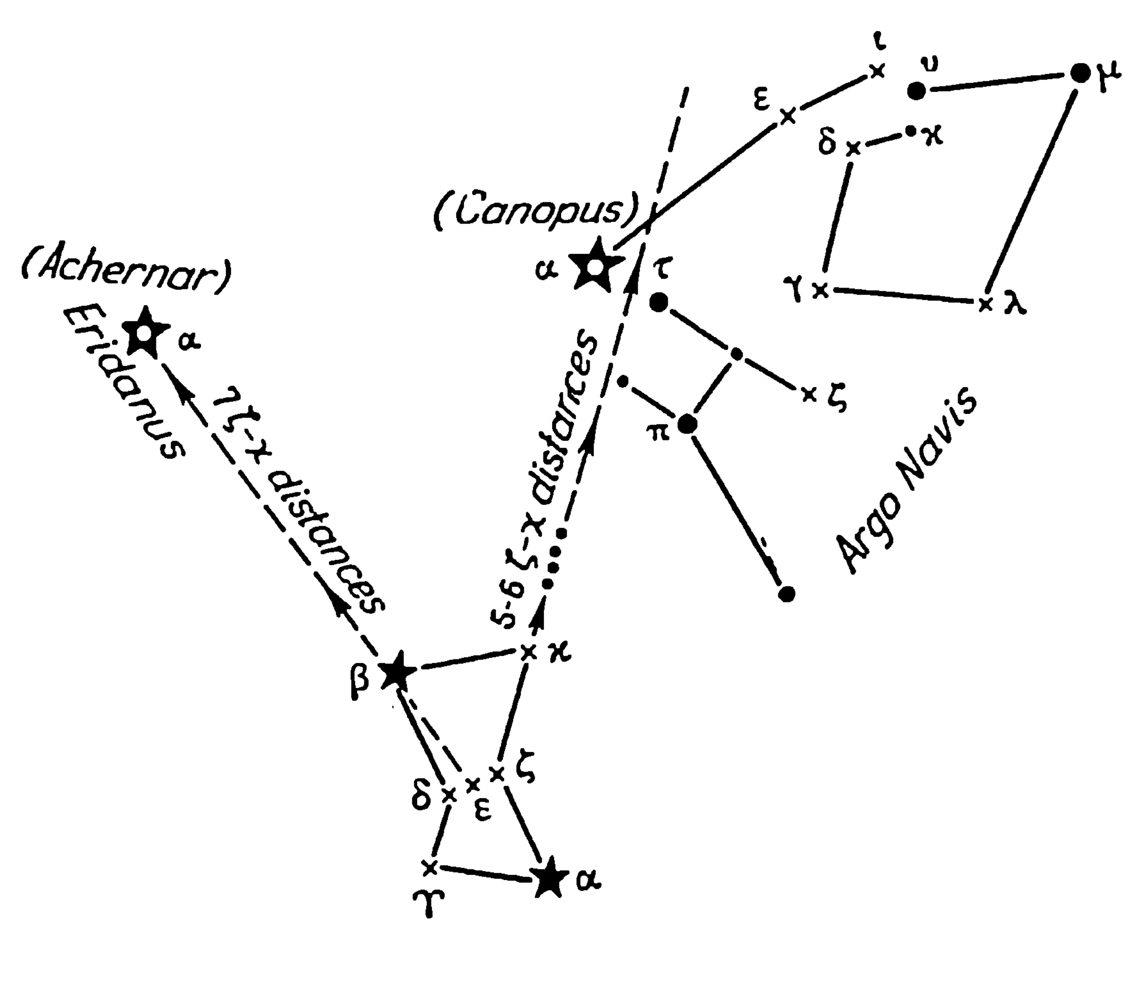
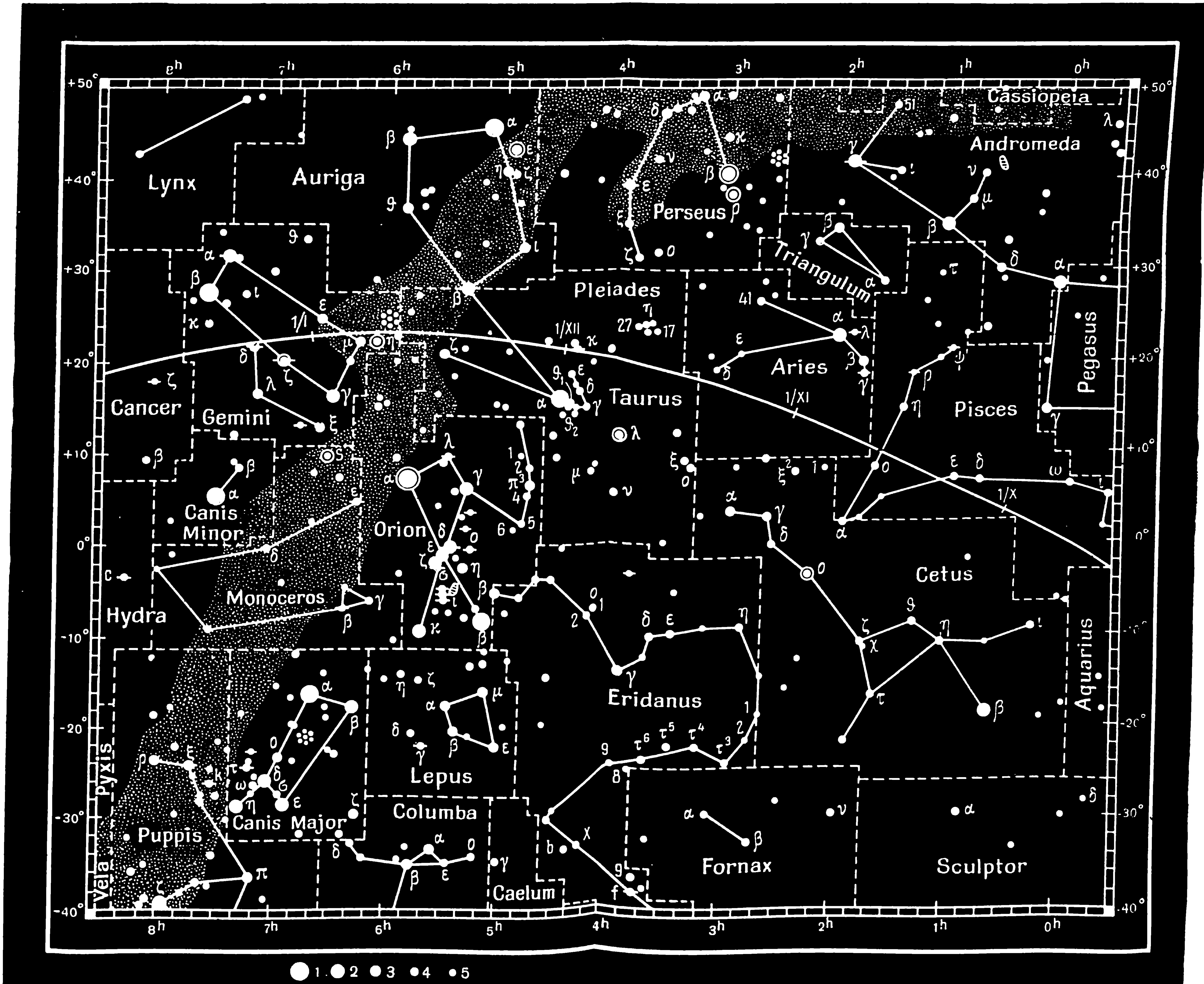


Fig. 53.



Lynx
Auriga
Perseus
Cassiopeia
Andromeda
Triangulum
Pleiades
Aries
Pisces
Pegasus
Taurus
Cancer
Gemini
Canis Minor
Orion
Monoceros
Hydra
Cetus
Eridanus
Aquarius
Lepus
Columba
Canis Major
Puppis
Pyxis
Vela
Caelum
Fornax
Sculptor
1/XII
1/XI
1/X
1/I
1 2 3 4 5

radio observation with radio telescopes. So far there are no "call signals" of artificial origin, but let us be patient, for the experiment has only just begun.

There seems to be some hope of success, the point being that Epsilon Eridani is much like the sun. It is a single star, rather cool, even somewhat cooler than the sun, comparable with it as to dimensions and mass, and is in slow rotation on its axis. This latter circumstance may be regarded at least as indirectly suggestive of a planetary system around Epsilon Eridani. The star is a bit closer to us than Tau Ceti: only about 3 parsecs away. When future generations begin to conquer the galactic environs of the sun, Epsilon Eridani will most likely be included in the plans of the first interstellar expeditions.

CONSTELLATIONS OF THE SPRING SKY

How dark the spring nights are. Three months ago at this same hour the southern half of the sky was studded with seven of the brightest stars. And now only three first-magnitude stars are left shining brilliantly on the background of just a few faint spring stars.

April 15, 10 p.m. A bit to the right of the celestial meridian and nearly midway from the south point to the zenith is the constellation Leo, in which we can easily pick out the silhouette of the mane and body of the king of animals. The principal star of this constellation is Regulus.

Two bright stars are visible in the southeast. The one above and somewhat brighter is the orange star Arcturus, the brightest of the spring stars and the principal star of Boötes. A bit lower and to the right of Arcturus is the bluish star Spica, chief in the constellation Virgo. Leo, Boötes and Virgo are the most important and most impressive of the spring constellations (see Appendix IX).

To the right of Leo is the constellation Cancer; above Leo is the inconspicuous tiny constellation Leo Minor. To the right of Boötes one can see the constellations Canis Venatici and Coma Berenices; to the right of Virgo, and slightly below it, we find an irregular quadrilateral made up of stars of almost the same brightness that form the constellation Corvus. In the long straggling constellation Hydra it is easy to find only the comparatively bright star Alpha Hydrae (second magnitude). But Crater and Sextans, which fit in between Leo and Hydra, are so unimpressive that it is simply impossible to find any clear-cut outlines. Below Spica to the left, low on the horizon, are two stars: Alpha and Beta Librae of Mag. 2.8 and 2.6, respectively.

Some of the spring constellations have names of curious

origin. Leo immortalizes the Nemean Lion, strangled by Hercules in one of his twelve labours. Incidentally, we find here another victim of Hercules' prowess: the Lernaean Hydra. In his struggle with this nine-headed monster, Hercules displayed great inventiveness and despite help given to Hydra by the mammoth Cancer (which has likewise found a place in the spring skies) he finally vanquished them.

We already know the story of Boötes, the son of the nymph Callisto. The origin of the constellation Virgo is not quite clear. According to one of the ancient versions, it is the goddess of agriculture Ceres. At any rate, the old star maps depict celestial Virgo as holding a ripe spike—the star Spica—in her hand.

There is an amusing legend connected with the constellation Coma Berenices. The Egyptian King Ptolemaeus Evergeta (third century B.C.) had a beautiful wife, Queen Berenices. She had magnificent hair that fell low down around her waist. When Ptolemaeus went off to war, his saddened wife took an oath to the gods to sacrifice her hair if only the gods would save her dear husband and return him unharmed.

Soon Ptolemaeus returned safe and sound and was terribly upset to see his wife shorn of her beautiful hair. The astronomer Conon calmed the king and queen by saying that the gods took Berenice's hair to the sky to beautify the heavens eternally.

The constellation Libra is one of the most ancient, but we are not sure what made the ancients place this simplest of measuring instruments in the sky. It might be that Libra and Virgo (with the spike Spica) reflected the mundane interests of the ancient traders and farmers.

On old maps of the sky, Corvus and Crater lie on Hydra. The Crow (Corvus) picks at The Hydra, and The Bowl (Crater) looks very tipsy, ready to fall at any moment. What could this strange combination of totally different objects mean? No one recalls any traces of the origin of these most ancient of constellations. True, there is a story to the effect that it was in this spot of the firmament that the crow was placed which was sent by Apollo with a bowl for water to perform some religious rite. The crow did not fulfill Apollo's wish, and so as punishment it was forever placed on the back of the loathsome snake-like celestial monster together with the bowl.

The remaining three constellations of the spring sky—Leo Minor, Canes Venatici, and Sextans—are of very recent origin. They were introduced in the seventeenth century by Hevelius, who, as we recall, was extremely inventive but never with good reason.

Leo Minor was put in the sky for astrological reasons. Astrologers attributed evil influence to the two celestial Bears, Ursa Major and Ursa Minor, and to Leo, The Lion; and so as not to upset tradition, Hevelius placed between Leo and Ursa Major an animal with just as pernicious an influence—a cub lion, or Leo Minor.

In the heavens where we now see the constellation Canes Venatici, Hevelius drew two dogs attacking The Great Bear. Since Hevelius put the leashes of these dogs in the hands of Boötes, it turns out that the son of Callisto is for some unknown reason setting the dogs on his mother. This strange invention of Hevelius is more like a prank than a reasonable innovation.

Completely out of place is Sextans, The Sextant, which Hevelius placed at the feet of Leo, The Lion. Hevelius remained true to style. This is how he explains it: "Its place is here not because the configuration of stars resembles this instrument and not because it suits the position but because it served me in verifying the positions of stars between 1658 and 1679, and evil humans destroyed it together with my observatory and everything that I had, putting it to the flames of a terrible conflagration. That is why I placed this work of Vulcan to the honour and glory of Urania, and astrologers will find that this monument is rightly placed between Leo and Hydra, both fierce animals."

We should not blame Hevelius too much, for he took advantage of the right of the discoverer, the right to give any name to a newly discovered object, and he little worried that future generations would find it hard to understand his reasons.

LEO, The Lion

We shall first make the acquaintance of Regulus, the chief star of this constellation. In the list of the twenty brightest stars of the sky, Regulus takes last place. This is a hot white star with a surface temperature of about

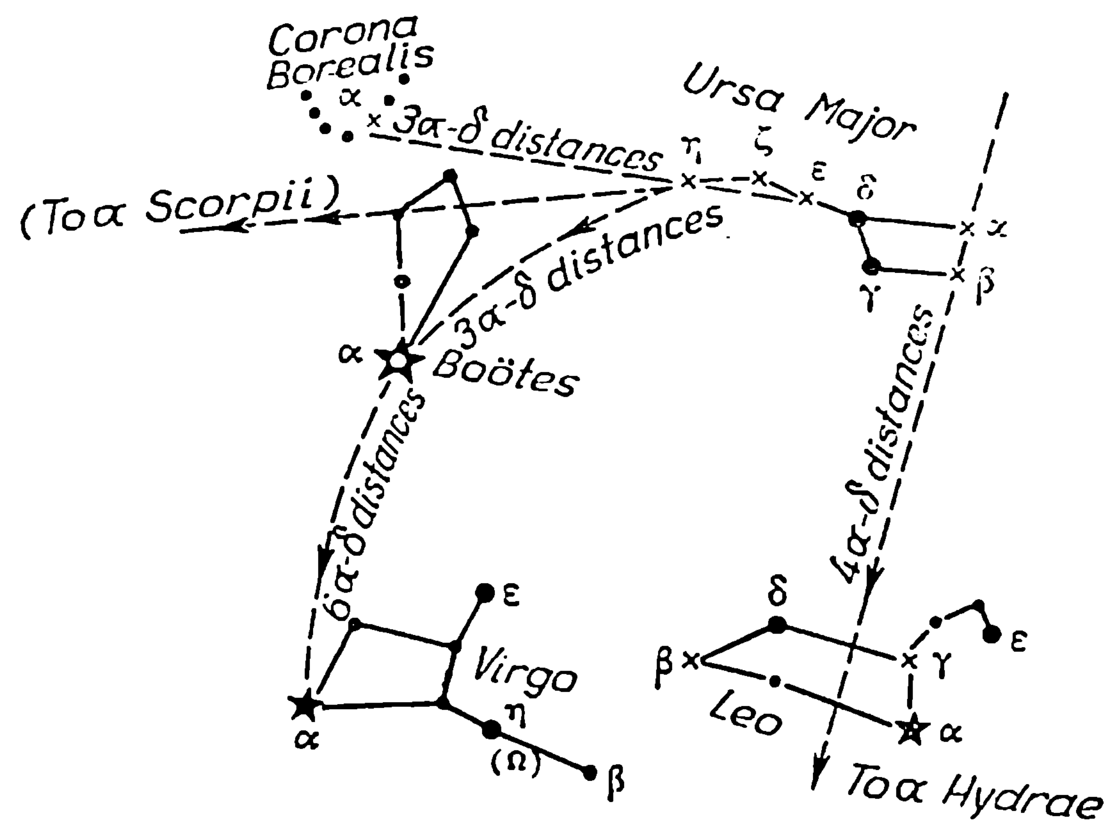


Fig. 54.

14,000°; it is 140 times as luminous as our sun. At the distance of Sirius, Regulus would appear six times as bright as this brightest star of the heavens. But since Regulus is ten times farther away than Sirius, its apparent magnitude is only 1.3.

Regulus is a large star—2.8 times the solar diameter. A telescope will reveal this body to be a double star, the companion, 177″ of arc away, is a yellow star of Mag. 7.6 and physically much like our sun. Although no orbital motion has yet been detected, the common features of the motions proper of Regulus and its sun-like companion star suggest that both stars are physically related. But Regulus has yet another companion, a faint thirteenth-magnitude star, which to all appearances seems to be a white dwarf of the same type as the Puppy Star. Three totally unlike stars connected into a single physical system. These eccentric families continue to stump astronomers.

On the other hand, there is a very ordinary double star Gamma Leonis. The orange and yellow stars (Mags. 2.6, and 3.8) are separated by 4″ of arc. The orbital motion has long since been studied and found to have a period of 619 years.

We find a smaller period (181 years) of revolution about the common centre of gravity in the double-star system Iota Leonis. The two hot bluish-yellow components are

separated by only 45 astronomical units, which is less than the distance from the sun to Pluto.

The constellation Leo has some interesting galaxies, but they are beyond the range of school telescopes.

LEO MINOR, The Lesser Lion

This constellation, by the whim of Hevelius, includes a score of faint stars, not a single one of which could attract our attention.

VIRGO, The Virgin

The chief star is Spica, which is brighter and hotter and much larger than Regulus. Six hundred suns shining together would produce the flux of radiation emitted by Spica. Alongside it our sun would appear small and insignificant.

Although Spica is farther away than Regulus (48 parsecs), it is somewhat brighter (Mag. 1.2). A telescope does not reveal any companion stars about Spica, but photoelectric measurements have picked up very slight fluctuations of amplitude (Mag. 0.1) and strictly periodic oscillations of brightness. Spica is an eclipsing variable. This is a very close couple with a period of only 4 days.

A very interesting star is Gamma Virginis (Fig. 55), a binary star consisting of two yellowish-white twin stars that are practically identical physically. They are separated by about 5″ of arc and in 1718 Bradley had already made a thorough study of this pair. Since then the stars have gone through nearly one and a half orbits about their common centre of gravity, because the period of this physical system is equal to 172 years. The centres of the stars are separated by an interval of 44 astronomical units, and the whole system is at a distance of 10 parsecs.

In the upper part of the constellation Virgo, in a portion of the sky bounded by the stars Epsilon, Delta, Gamma, Eta, Beta, and Omicron, is an enormous concentration of galaxies. Large telescopes reveal here a "system of systems", a fantastic assemblage of galaxies totalling about two and a half thousand stellar islands (island universes) like our own. The centre of this cloud is four million parsecs from

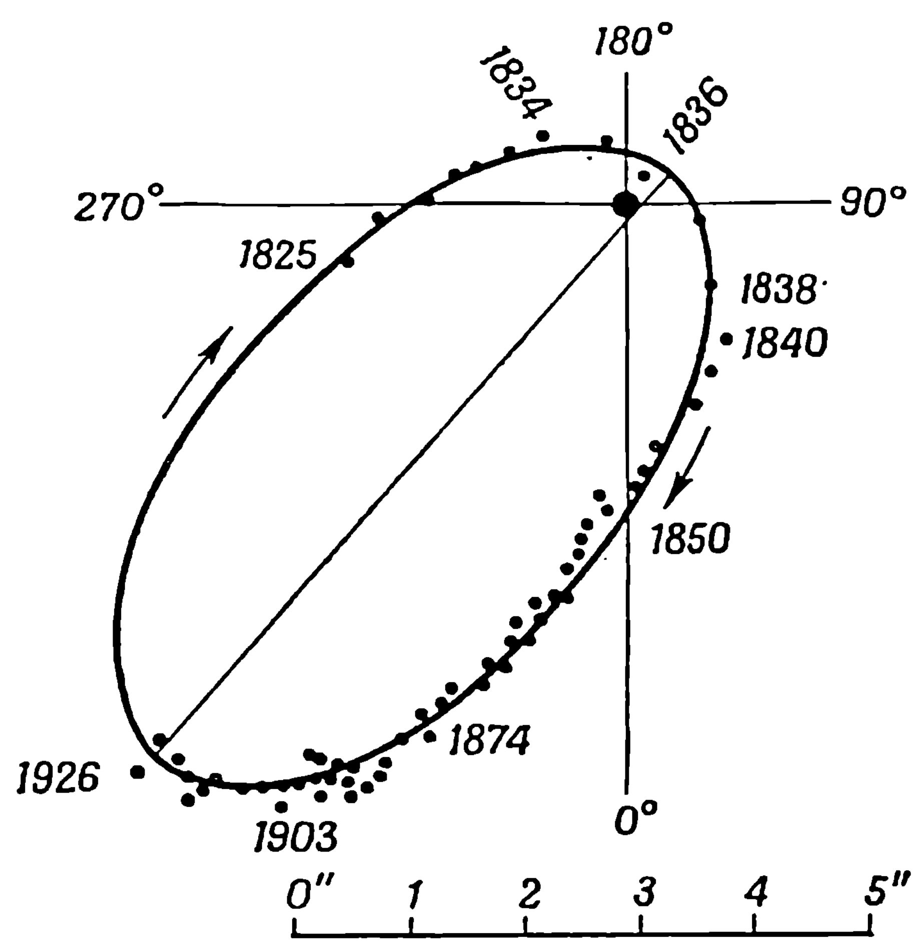


Fig. 55. Orbit of the binary star Gamma Virginis.

us and the whole system is racing away from us, in accord with the famous red-shift law, with a velocity of 1,200 km/s.

Unfortunately, even the brightest of the galaxies of this cloud has an integrated brilliance of about Mag. 10 and they are therefore beyond the range of any school telescope.

CRATER, The Bowl

There is simply nothing interesting in this constellation that borders on Virgo and consists of twenty naked-eye stars.

CORVUS, The Crow

Of the four stars Delta, Beta, Epsilon and Gamma that make up the outline of Corvus, the first and brightest (Mag. 3) is a binary star. The large school refractor reveals, 24″ of arc away, a companion red star of Mag. 8. The brightest star of all is Gamma Corvi, of Mag. 2.6. This is a hot white giant at about the same distance from us (40 parsecs) as the physically similar star Delta Corvi.

SEXTANS, The Sextant

There are no sights for us in this constellation of 25 stars.

BOÖTES, The Shepherd

The principal star of the constellation Boötes is Arcturus, the first star detected in daylight with a telescope. This was done in 1635 by a contemporary of Galileo, the French astronomer Moraine. In those times, one person frequently combined the professions of astronomer and astrologer. Moraine did too, he was one of the last astrologers of France and cast the horoscope of Louis XIV.

Today, anyone can repeat Moraine's observations, provided that he knows the position of Arcturus in the day sky with sufficient accuracy. Arcturus is a very bright star (Mag. 0.2), occupying sixth place in the list of the brightest stars of the heavens. Even the inexperienced observer is struck by the orange hue of Arcturus.

Compared with the sun, Arcturus is huge (26 times greater in diameter) and for this reason can be called an orange giant. However it is somewhat cooler than the sun (surface temperature about 5,000°), but its proximity to the earth (11 parsecs away) and its large size enable Arcturus to compete in apparent brilliancy with such titans as Capella.

Arcturus has a very considerable proper motion: in roughly 800 years it covers an angular distance equal to the apparent disc of the moon. It is therefore not surprising that Arcturus was the first star which Halley (in 1717) found to have an obvious motion in space. In those days any refutation of the false idea of the fixity of the stars was not only of purely scientific interest, it had a great philosophical impact as well.

The constellation Boötes has a number of interesting double stars. V. Struve, founder of the Pulkovo Observatory, considered Epsilon Boötis to be the most beautiful of all double stars. And it really is, a bright yellow primary of Mag. 3 and right next to it, about 3″ of arc away, is a bluish sixth-magnitude companion. The primary itself is, in addition, a spectral binary, which gives us a system of three suns, not two.

The star Pi Boötis consists of two hot blue stars (Mags. 4.9 and 5.8) separated by 5″.6 of arc. Each of them, if to judge by the spectrum, is in turn a double, which gives us a quadruple star.

In a telescope it is easy to resolve the beautiful double star Xi Boötis. The primary is an orange star of Mag. 4.9 that has a companion of Mag. 6.8 at a distance of 5″.3. In this pair the components are separated by only 32 astronomical units; the period of revolution is 150 years.

A truly remarkable star is the binary system Zeta Boötis made up of two hot blue stars (of Mag. 4.6) revolving about a common centre of gravity in 123 years along an extremely elongated orbit (the eccentricity is 0.96). It is too bad that the components are separated by an interval of only 1″.2 so that a school telescope cannot resolve them. Right next to Epsilon Boötis is a reddish fifth-magnitude star designated W. Some observers claim that this star fades at times to Mag. 5.4. Others have never noticed any change in brightness at all. To this day we do not know for sure whether it is a constant or variable star. Perhaps the reader will help us to solve this problem.

LIBRA, The Balance, or The Scales

There are two sights in this small constellation. The first is Alpha Librae, the second brightest star in Libra after Beta Librae. A field-glass already reveals that the primary hot blue star (Mag. 2.8) has a yellowish companion of Mag. 5.3 at a short distance of 5′ of arc. The two stars have similar proper motions, but the enormous distance between them casts doubt on their being a physically related system of stars.

The star Delta Librae is a well-studied eclipsing variable with a number of specific features. Both components are of nearly the same size (radii: 2.4 and 2.5 million km). But the smaller one is a hot blue giant 2.7 times more massive than our sun, while the larger one is a yellow giant much like Capella, but only 1.2 times the solar mass. The centres of these stars are separated by a mean distance of only 8.6 million km; the period of revolution is 2.33 days. An earth-bound observer can sometimes see Delta Librae fade from Mag. 4.8 to 5.9. Since the yellow star is not so luminous as the blue one, there is a secondary minimum about Mag. 0.1 deep.

CANES VENATICI, The Hunting Dogs

The reader is by now so used to arbitrary names for various constellations that he will probably not be surprised to learn that Alpha Canum Venaticorum was once known as Cor Caroli, Charles' Heart. Yes, the same King of England, Charles II, who did everything to avenge the supporters of Cromwell for the killing of his father. It was the monarch-minded Edmund Halley that put this vengeful "heart" in the sky; it was due to his efforts that the star maps of that period depicted a crown on a heart under the tail of The Great Bear.

Halley's invention did not last for long, but the star so fancifully named is quite worthy of our attention. This is undoubtedly one of the most remarkable stars known to astronomers.

First of all, Alpha Canum Venaticorum is one of the most beautiful double stars. The primary is a hot blue giant of Mag. 2.9 with a yellowish companion (Mag. 5.4) 20″ of arc away. Each of these stars is in turn a spectral binary with a period of several days. But the most curious thing of all is that Alpha Canum Venaticorum is a magnetically variable star.

Comparatively recently, in a fine analysis of the spectrum, this star was found to have a very strong and, what is more, variable magnetic field whose intensity fluctuates between minus 4,000 and plus 5,000 gauss (the sign indicates the direction of the field). Compare this with the strength of the sun's magnetic field which does not exceed 50 gauss.

When discussing galaxies, astronomy books usually give photographs of the Andromeda Nebula and the nebula in Canes Venatici (see Fig. 5). In Messier's catalogue it is numbered 51, M51. It is very effective with the magnificent spiral seen flat-on. Despite the static character of photographs, the structure of the galaxy creates the impression of being very dynamic. There is another strange feature. At the end of the spiral arm of the galaxy (moving downwards in the photograph) we see a curious condensation, a sort of appendage that definitely spoils the harmony of the general picture.

Only recently the noted Soviet astronomer B. A. Vorontsov-Velyaminov succeeded in proving that the photographic

Fig. 56. The double galaxy M51.

plate recorded not one but two galaxies connected by this common spiral arm. Vorontsov-Velyaminov discovered in the depths of the Metagalaxy several other double and connected galaxies remarkably similar to M51. Thus, what we see in Figs. 5 and 56 is no freak of nature but a certain regularity, a definite stage in the evolution of (at least some) galaxies.

The other interconnected and interacting galaxies are very far away and come within the range of only powerful telescopes. But M51 is relatively close ("only" 2,500 kiloparsecs away), and its apparent integrated brightness is of

Mag. 8.9. This double galaxy is well worth locating in the sky, and although school telescopes will of course not show the richness of detail that we find in Fig. 5, it will be exciting to see a faint hazy patch, the light of thousands of millions of stars reaching us after a journey that has lasted over 8 million years!

The primary galaxy of this pair is one-fifth the diameter of our Galaxy. In the sky both M51 galaxies are seen as a nebulous spot 14′ of arc across, which is just about one half the apparent diameter of the moon's disc. The double galaxy M51 is racing away from us at 426 km/s—so says the red shift in its spectrum.

Canes Venatici has (at Declination 28° 53′, Right Ascension 13h 37m.6) a comparatively bright (Mag. 7.2) globular cluster M3. Its apparent diameter measures 22′ and it is distant from us 14 kiloparsecs. The lines in the spectrum of the cluster are shifted to the violet, which means that the M3 cluster is approaching us and with quite a velocity, 150 km/s.

COMA BERENICES, Berenice's Hair

It is worth taking a close look at this constellation first with the unaided eye and then with binoculars. In the right half there is a large group of faint stars that resemble a flock of crane. Perhaps, like Conon, we can picture here a shock of magnificently scintillating hair of the beautiful Berenice. But we would like to point out that inside this "flock" and along the boundary lines powerful telescopes reveal a tremendous number of galaxies. Here in Coma Berenices is yet another cloud of galaxies, only slightly smaller than the cloud in Virgo: 1,000 stellar systems as against 2,500. But it may be that many galaxies in the cloud of the constellation Coma Berenices are not visible simply because they are too faint to be seen—remember, this cloud is 25 million parsecs away! Again, by the law of the red shift, it is receding from us at the staggering speed of 7,400 km/s.

After this fantastic picture (which, unfortunately, is within the range of only the most powerful telescopes), let us turn to the star Alpha Comae Berenices. Right next to this modest fifth-magnitude star, school telescopes will pick up the globular star cluster M53. It has an integrated bright-

ness of 8.7 and an apparent diameter of 16′. The cluster is moving away from the earth with a velocity of 100 km/s and is already distant 20 kiloparsecs.

HYDRA, The Hydra

Below Spica some 10° we can sometimes see two stars of about the same brilliance (Mag. 3), sometimes only one, the brighter. This is Gamma Hydrae, the other fainter one that is not always visible to the naked eye is the long-period variable R Hydrae.

This is an enormous and very cool star with bright emission lines in its spectrum and is, physically, much like the star Mira Ceti. The amplitude of brightness variation in R Hydrae is very great: from 3.5 to 10.9. The peaks of brightness are separated by a time of 387 days, just about one terrestrial year. R Hydrae is a typical long-period variable, and everything that was said about the reasons for the oscillations of brightness of Mira Ceti (see p. 114) fully applies to R Hydrae as well.

Near the star Mu Hydrae is a planetary nebula, but due to its faintness (Mag. 9.7) and tiny apparent diameter (only 0′.7) it can be found only in rather large telescopes. At best, school telescopes reveal a barely perceptible nebulous point of light.

CANCER, The Crab

Let us try to find Gamma and Delta Cancri, two of the very brightest stars in this otherwise faint-star constellation. Between them and a bit to the right is a nebulous star clearly seen with the naked eye. No matter how keen-sighted you are, this strange fuzzy object, called Epsilon in olden times, will not reveal the slightest structure.

Nevertheless, Epsilon Cancri is not a star, but one of the most remarkable of the open clusters of our skies. From time out of memory it has been known as the Beehive, Praesepe.

Praesepe—the celestial Beehive—is a minute cloudlet and in ancient times was considered a good indicator of the weather, though modern meteorology thinks otherwise. Only Galileo was able to figure out what this patch of haze really

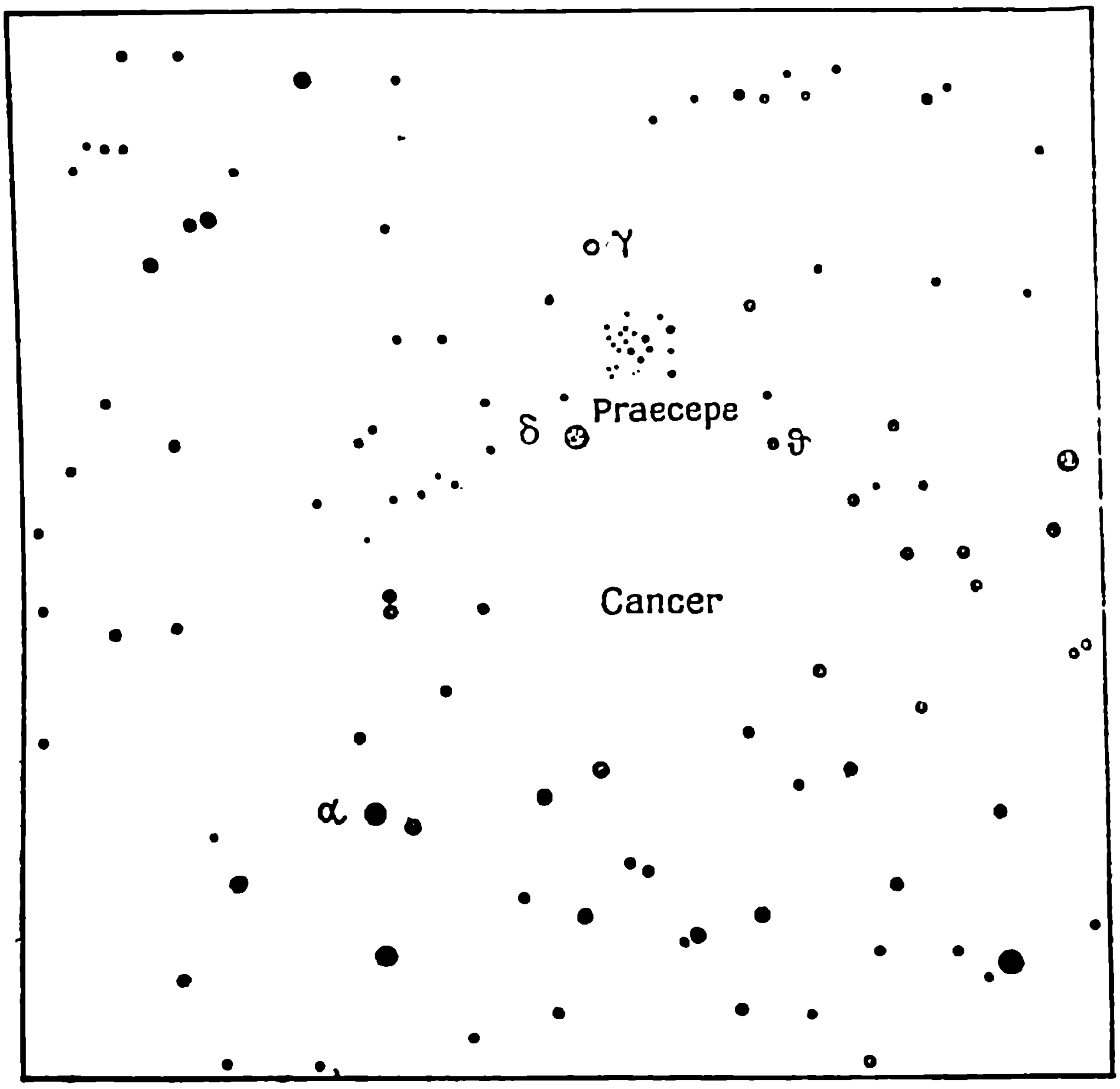


Fig. 57. The star cluster Praesepe.

represents. In the field of his telescope the Beehive broke down into a multitude of faintly glowing stars (Fig. 57).

Take a look at this swarm of stars in a pair of binoculars or a low-powered telescope and you will understand Galileo's excitement when words failed him to describe this magnificent spectacle.

Praesepe is a typical open star cluster (designated M44). It is only a little farther away than the Pleiades (160 parsecs). The hundred or so stars that make up the Beehive occupy in space an area about 5 parsecs across. Telescopes reveal stars in the Beehive between sixth and eleventh magnitudes, most of them being hot white giants with a slight admixture of cooler stars like our sun. Both of these star clusters are far inferior in spatial density (number of stars per unit volume) to the very dense globular star clusters, particularly in the central regions. Cancer has yet another open star cluster, M67. It lies just a little way to the right of Alpha Cancri and is very easy to locate.

Here is the full identification card of this stellar swarm. Distance: 800 parsecs, diameter: about 4 parsecs. M67 has 80 stars from tenth to fourteenth magnitude, most of them (like in the Beehive) are hot white giants.

Praesepe and M67 are twins. But how different they appear to the terrestrial viewer! Praesepe is seen clearly to the naked eye as a nebulous star of Mag. 3.7; M67 has an integrated brightness of Mag. 7.3 and appears as a brightly glowing spot in the school telescope. The reason for this is distance: Praesepe is nearly 6 times closer than M67.

The constellation Cancer has a remarkable multiple star Zeta (ζ) Cancri. The ancients regarded it as a single star, and quite an ordinary one, of the fifth magnitude. In 1656 Tobias Mayer, whose name was mentioned in connection with the Andromeda Nebula, resolved Zeta Cancri. In 1781, after the observations of William Herschel, Zeta Cancri was considered a triple star. Today we know that the outwardly modest little star Zeta is actually a complex system of five stars—a quintuple!

The principal yellow star A (Mag. 5.7) is like our sun and at a distance of $1''.2$ of arc away there is a hot blue companion of Mag. 6.0 (star B). Six seconds of arc from star A is a tiny sixth-magnitude star C, which in turn has a companion star of Mag. 7.8 (star D). Finally, spectral analysis shows that star B has a companion too, star E.

This whole complicated system of five stars has been thoroughly studied and we know the periods of revolution of the different pairs. For instance, stars A and B orbit about their common centre of gravity in 60 years. Star C circles about them with a period of 1,137 years, and turns (together with D) round a common centre of gravity with a period of 17.6 years. That is how complicated things can get, simple though they may be on the surface.

Turn your telescope to this most complex of naked-eye spring stars. What do you think you will see in your field of view?

CONSTELLATIONS OF THE SUMMER SKY

Short light summer evenings are the worst time of the year for astronomers. In the northern latitudes we have the so-called white nights and, of course, no work at all, as far as viewing the stars is concerned.

This time we shall change our system and record the time of 23:00 hours on July 15. In the middle latitudes of the Soviet Union the sky is still rather light at this time, so only the brightest stars are visible. But we shall describe all the sights of the summer constellations, even the faintest objects, in the hope that the reader will be able to locate them and take a better look at the end of spring or on the dark nights of August and September.

On a light twilight summer sky, the first stars to come out are three bright stars, Vega (Alpha Lyrae), Deneb (Alpha Cygni) and Altair (Alpha Aquilae). They form the vertices of an enormous "summer triangle", the chief feature of our northern summer night sky.

On dark nights in August, next to the bluish Vega and a bit lower one can see four faint stars that form the vertices of an imaginary parallelogram. This is the small constellation of Lyra, The Lyre, the musical instrument once played upon by Orpheus, the mythical musician that even held the dwellers of Hades spellbound. The characteristic feature of the constellation Cygnus is a cross, the tip of which is marked by the white star Deneb. Old star maps show Cygnus, The Swan, flying down to earth. The Greeks claimed that this was the mighty Zeus, hiding from the jealousy of Hera and flying to a tryst with Leda, the future mother of Castor and Pollux.

Not far from Altair, above and below this bright blue star, are two bright stars, Gamma and Beta Aquilae. They

form, together with Delta Aquilae to the right, the characteristic figure of this small constellation. According to ancient Greek legends, here in the sky is immortalized the vulture which for 10,000 years had consumed the liver of Prometheus bound to a rock—the hero Prometheus who took from Olympus the light of knowledge and bestowed it upon man and who for this act was punished by the enraged gods.

To the right of Lyra is the constellation Hercules. Star maps show his characteristic figure. Hercules it was—mighty hero of old—who cudgeled to death the fierce Nemean Lion and strangled the many-headed Lernaean Hydra and performed ten other great labours. Hevelius' picturesque seventeenth-century map of the sky shows Hercules strangling the Hydra with a mighty hand that is already carrying the skin of the Nemean Lion. It is not clear at all why tradition has Hercules pictured upside down among the other constellations.

Under Hercules are Ophiuchus and Serpens, two rather irregularly outlined constellations. These extremely ancient constellations are apparently unrelated by any myth and depict only what their names indicate: The Snake-Strangler and The Serpent.

But the neighbouring constellation Corona Borealis is featured by a tiara or hoop of stars at the head of which is Gemma (Alpha Coronae Borealis) and has a beautiful legend to go with it.

The beautiful Ariadne, captured by the mythical hero Theseus and then pitilessly forsaken by him on the sea shore, was crying out for help. Finally, the god Bacchus appeared, and wishing to immortalize the memory of the sufferer, took the wreath from the head of Ariadne and threw it into the sky. While in flight, the precious stones turned into stars, which from that time on form the constellation Corona Borealis.

In the southern part of the celestial sphere, in regions close to the horizon we see a chain of ancient constellations Aquarius, Capricornus, Sagittarius, and Scorpio with the bright red star Antares. These constellations do not have any conspicuous features and are usually found by proceeding from individual stars.

Like Ophiuchus, Aquarius (The Water Bearer) does not signify anything more than the name indicates: simply a man pouring water. The neighbouring constellation of Capri-

cornus portrays a mythical animal, a cross between a goat and a fish. At any rate, the being depicted on pictorial star maps in this region of the sky has the head of a goat and a scales-covered fish-tail.

The constellation Sagittarius is of more definite origin. It portrays the Centaur Hiron, a mythical half-man half-horse and hero of many legends engendered by the poetical imagination of the ancient Greeks.

It is hard to say what caused the ancient observers of the sky to introduce the constellation Scorpio. At any rate, Scorpio is one of the most ancient of the constellations. In the legend about the tragic fate of Phaëthon, son of Helios the sun, who perished for disobeying his father, we learn that it was a celestial Scorpion that frightened the youth and was the direct cause of his death.

In the summer sky there are a number of small and outwardly inconspicuous constellations, such as Delphinus, Equuleus, Vulpecula, Sagitta, and Scutum.

Of these constellations, Delphinus is the most prominent. Its characteristic figure is a small diamond-shaped quadruple of stars with a tiny chain of three faint stars moving downwards on the right. Just a little imagination is required to see the enormous head of a dolphin and the tail drooping towards the horizon.

Upwards from Delphinus and to the right, immediately over Altair, is a constellation, Sagitta, in which the stars Gamma, Delta, Alpha and Beta form something like the tailpiece of a flying arrow.

Both these small constellations are very ancient, just as old, say, as The Great Bear, Orion or Cassiopeia. The other constellations are much younger.

Equuleus, The Little Horse, was first mentioned in the catalogue of the famous astronomer of antiquity Hipparchus (first century B.C.). It is hard to say what compelled Hipparchus to introduce this constellation but since that time the star maps carry the upturned muzzle of a colt right next to the winged horse of Pegasus.

The constellations Vulpecula and Scutum were invented by Hevelius (1690). The former was proposed because, said Hevelius, "the fox is an animal of guile and gluttony like the eagle", and so it is quite natural for them to be side by side in the sky. As for Scutum, patriotic sentiment got the better of the Polish astronomer—Hevelius called it

Scutum Sobieskii (The Shield of Sobieski). This is the only constellation in the sky that is associated with a concrete historical personage: the Polish King and general John Sobieski.

LYRA, The Lyre

The famous planetary nebula in the constellation Lyra is reminiscent of a smoke ring, but the analogy ends there, for the Lyra Nebula is not a ring at all but a cosmic structure more like hollow thick-walled and somewhat flattened gaseous sphere. Round the fringes (Fig. 58), the line of vision pierces a greater thickness of the nebula than in the centre, that is why the edges appear brighter. But the central regions of the nebula are much brighter than the surrounding black background of the sky. So here again we see gas emitting light.

On a coloured photograph, the edges of the planetary nebula of Lyra are a reddish-crimson, while the central

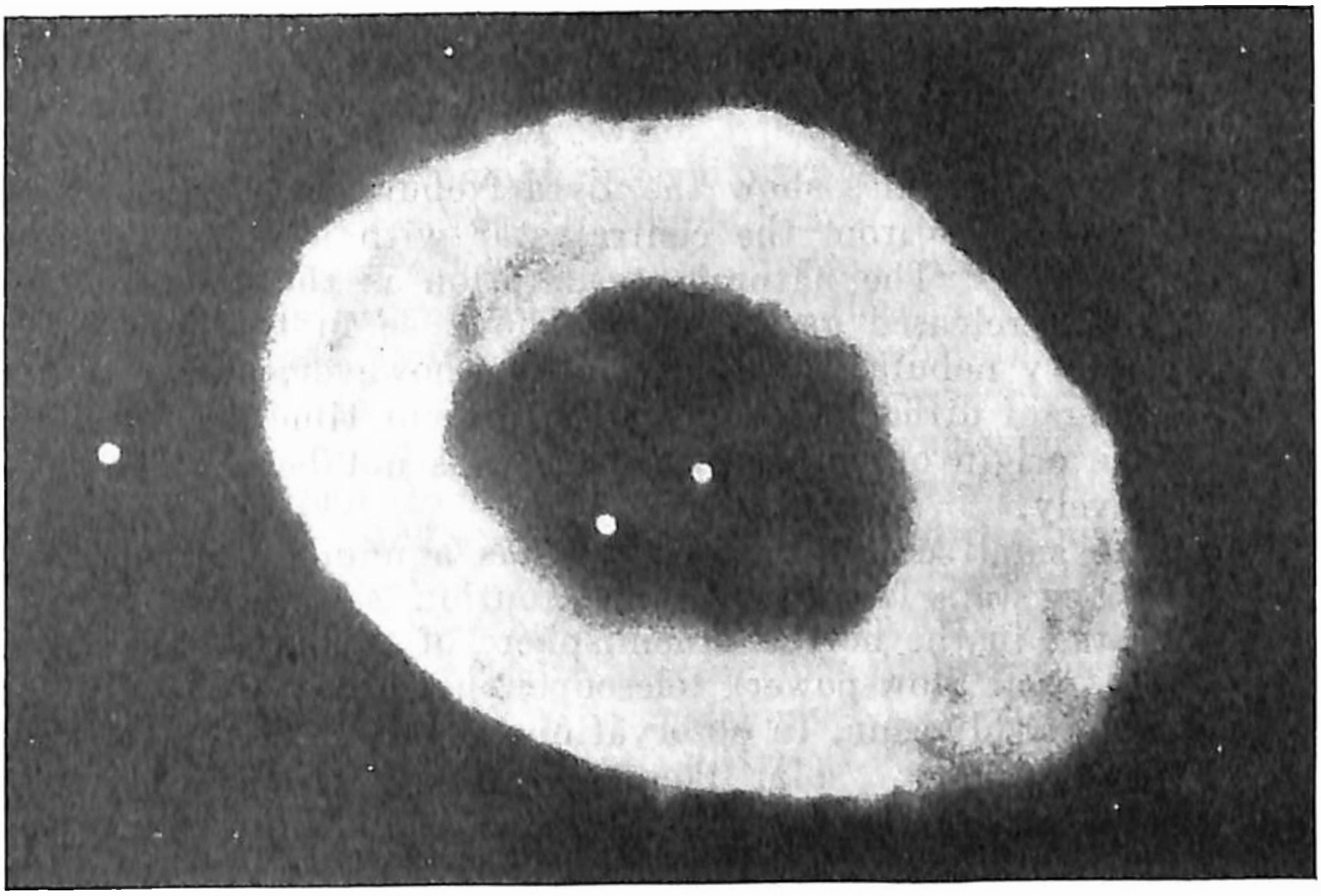


Fig. 58. The planetary nebula in Lyra.

regions are greenish. The colour is due to the gases that make up the nebula. The red belongs to hydrogen, the green is due to emissions of highly ionized oxygen. Part of the radiation is generated by helium atoms. This is cold radiation, the gases of the nebula luminesce under the light of the central star.

The photograph shows several stars, but only the central one is related to the nebula. The others make up the stellar background, some of them are closer than the nebula, others are farther away.

The central nucleus of the Lyra Nebula is a star with exceptional characteristics. It has a surface temperature of 75,000° and is rightly considered one of the hottest stars. Its powerful ultraviolet radiation makes the gases of the nebula luminesce; in visible rays the Lyra Nebula is many tens of times brighter than its marvellous nucleus.

It is easy to find the planetary nebula, for it lies nearly midway between the stars Gamma and Beta Lyrae. In a school telescope it appears as a small oval luminous nebulosity. The real dimensions of this object are very impressive: the mean diameter of the Lyra Nebula is close to 70,000 astronomical units, which is almost 700 times that of the solar system! But at its distance of 660 parsecs the Lyra Nebula has a mean apparent diameter of only about a minute of arc.

Spectral studies show the Lyra Nebula as expanding in all directions from the central star with a velocity close to 19 km/s. The natural presumption is that the central star has released gases that we now see in the form of a planetary nebula. This explanation, however, encounters a number of difficulties and at the present time the problem of the origin of planetary nebulae has not been solved definitively.

The small constellation Lyra has a number of very interesting stars. In the centre of attention is Vega, the brightest star in the northern hemisphere of the sky (Mag. 0.1). Train your (low-power) telescope on it and you will see a faraway blue sun. In observations of this kind the theoretically derived "solar-likeness" of bright stars becomes almost physically tangible. Vega is a hot blue giant two and a half times the diameter of our sun. As far back as 1837, V. Struve determined the distance to Vega and obtained a figure close to the modern estimate (8 parsecs).

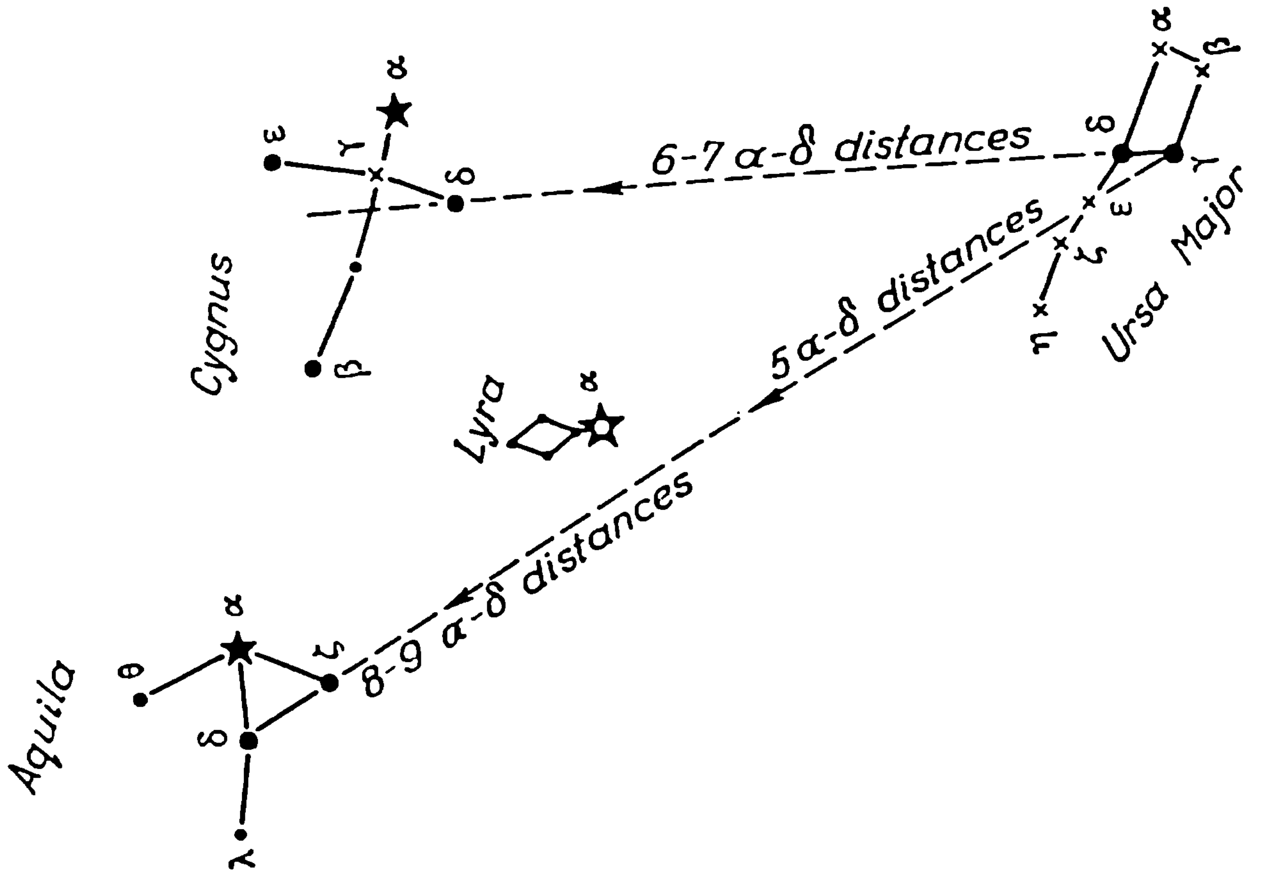


Fig. 59.

Physically, Vega is like Sirius but is somewhat larger and hotter.

Next to Vega there is a remarkable multiple star Epsilon Lyrae. A keen-sighted person will clearly see two stars of the fifth magnitude separated by 3′28″ of arc. This pair is particularly impressive when viewed in binoculars. A telescope will reveal that each of the components of Epsilon Lyrae is in turn a double star (the components being separated by 2″.8 and 2″.3 of arc). All four stars are blue giants resembling Sirius. And these four Siriuses form a physically related system of four suns! In each of the pairs the periods of revolution are incomparably shorter than the stupendous interval of time during which both pairs circuit their common centre of gravity.

The constellation Lyra has a number of interesting variable stars too. On the northern fringe of the constellation, not far from Vega, is the semiregular variable R Lyrae. This is a cool red giant with fluctuations of brightness between Mags. 4.0 and 5.0. The mean period is close to 50 days, though the time intervals between successive maxima and minima may be quite different.

Take your binoculars and look east of this variable and you will find another variable, RR Lyrae. It is a Cepheid, but somewhat different from Delta Cephei. The variable

RR Lyrae heads the class of *short-period Cepheids* with a period of brightness oscillation less than one day. By contrast, the "classical" Cepheids of the Delta Cephei type are called *long-period Cepheids* with periods in excess of one day.

RR Lyrae varies in brightness from Mag. 7.1 to 8.0. It oscillates very rapidly with a period of 0.57 day. During this time, changes occur both in the brightness and the spectral class of the star (from A2 to F0), and, naturally, the temperature.

The difference between short-period and long-period Cepheids is not confined solely to the period. There are more deep-seated differences. For one thing, type RR Lyrae stars are encountered at all imaginable distances from the galactic equator, whereas the classical Cepheids (type star: Delta Cephei) exhibit an obvious concentration towards the median equatorial plane of the Galaxy. In other words, Cepheids of the RR Lyrae type are stars of spherical subsystems, whereas Delta Cephei type Cepheids belong to stars of plane subsystems. This is evidence of different origin of the two classes of Cepheids, despite the outward similarity in the forms of the light curves.

However, the most remarkable variable of this constellation is the matchless (in many respects) variable Beta Lyrae. This star, the variability of which was detected by Goodricke, is the type star of a special subclass of eclipsing variables. Unlike Algol, Beta Lyrae is constantly changing brightness between Mags. 3.4 and 4.3 with a period of 12.92 days. There is also a clear-cut second minimum (Mag. 3.8) located midway between the main ones.

The observed light curve would appear to be quite nicely explained by the scheme of two ellipsoidal stars of different brightness revolving about a common centre of gravity. The total surface area presented by the two components of Beta Lyrae facing the observer is constantly changing, thus accounting for the continuous fluctuations in brightness. However, the very complicated form of spectrum of Beta Lyrae and its strange variations are not in the least compatible with this oversimple scheme. A great deal of effort was spent before the true nature of Beta Lyrae was deciphered.

This variable star, which appears single to the naked eye, actually consists of two very close-lying ellipsoidal

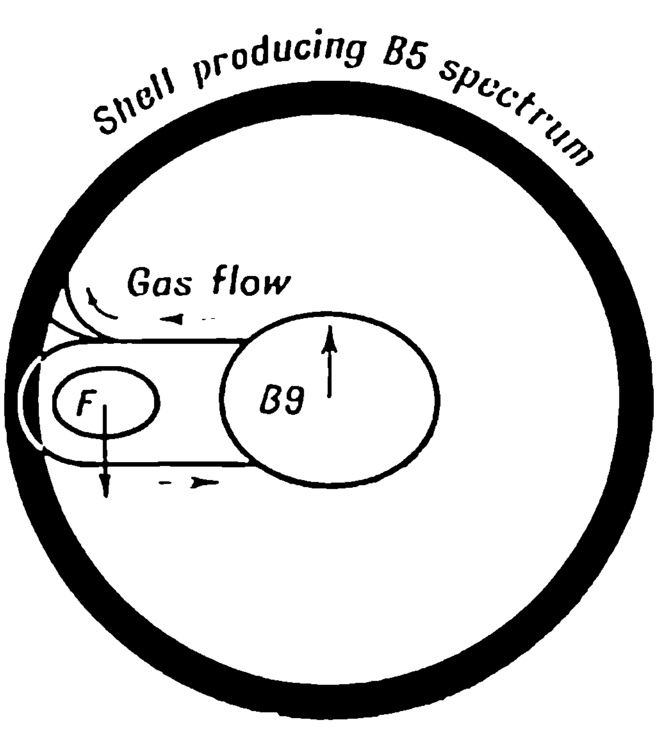


Fig. 60. The structure of the Beta Lyrae system.

stars. The larger one is a hot bluish-white giant with a surface temperature of about 15,000°. The smaller star is twice as cool (spectral class F) and its radiation is lost in the powerful fluxes of light emitted by the primary star. But that is not all. There is a constant streaming of gases from the primary to the companion with the gases flowing round the companion star and again returning to the primary (Fig. 60). However, the revolution of the companion star about the primary and the inertness of the gases result in a part of the gases ejected by the primary leaving the stars completely and forming an enormous gaseous spiral in space. Perhaps the reader will recall the whirling spark wheels of holiday fireworks. It might give some idea of what this is like.

The gaseous tail is continuously being scattered in space, but it is also receiving new portions of gas ejected by the primary star. The result is a kind of dynamic equilibrium, and the gaseous tail is always seen veiling the spectrum of Beta Lyrae. Quite accidentally, the line of sight is close to the plane in which this gaseous tail lies. If we saw Beta Lyrae from above or below, it would appear as a very ordinary constant star.

Gaseous tails have been found in a number of other stars, in some cases they take the shape of a ring. At a close distance such stars would resemble Saturn. True, both the gaseous rings and the gaseous tail of Beta Lyrae are unstable and they are kept in existence solely by the gas flows that are constantly erupting from the stars.

The Lyra constellation is an example of how a small asterism may sometimes contain a very large number of excellent sights within the range of observation of even school telescopes.

CYGNUS, The Swan

In Cygnus the first sight is the principal star Deneb. It is an enormous sun second only to Rigel. Six thousands of our suns would be needed to create the flux of radiation emitted into space by Deneb! This hot and very distant blue giant (it is 170 parsecs away) is 35 times the sun in diameter, but in our sky it is only a bright star of Mag. 1.3.

Near Deneb, alongside Epsilon Cygni, is a well-known diffuse nebula, the North America Nebula, named after the continent that it resembles. It comes within the range of photographic observation only in powerful telescopes and is at about the same distance away as Deneb, which causes it to glow. Cygnus has two more remarkable gaseous nebulae very much like cirrus clouds (Fig. 61). But unfortunately, these objects are all beyond the range of school telescopes. Still we can enjoy the beauty of the bright open star cluster M39 located a short distance from Rho Cygni. M39 is a star-poor cluster with only 25 hot white giants. In the sky it occupies an area equal to the apparent disc of the moon, actually it is 2.4 parsecs across and 260 parsecs distant. Besides Deneb, the constellation Cygnus has a number of interesting double stars. First of all, Beta Cygni, which lies at the base of the "cross" of the constellation. It is called Albireo. Once the reader gets a glimpse of this star, he will doubtlessly agree that Albireo is the most beautiful double (binary) star. The primary is an orange star of Mag. 3.2 with a hot white companion of Mag. 5.4 at a distance of 34″.6 of arc. Due to the physiological effects of vision, Albireo has a golden-yellow tint when viewed telescopically and its companion is blue. Despite the considerable distance between the components, this pair is a physical double—a binary—though the period of revolution is very great. Albireo is just a bit closer to us than Deneb: 125 parsecs distant.

Delta Cygni (the right tip of the "cross") is also a binary, but much more difficult to resolve. The distance between

Fig. 61. The nebula in Cygnus.

the primary blue giant (Mag. 3.4) and its 6.4-magnitude companion is only 2″.1. The period has been reliably determined and found to be equal to 537 years.

Of particular interest is the double star 61 Cygni. This is one of the first stars whose distance away from us was determined. It was done by Bessel in 1837. As one of his contemporaries put it, "for the first time, a sounding lead tossed into the depths of the universe has reached bottom". Only after the scientific feats of Struve, Bessel and others was it obvious that the stars are actually distant suns. This was experimental confirmation of the speculative ideas of Giordano Bruno.

The pair of stars in 61 Cygni is very close to the earth: only 3.4 parsecs distant. There are only about ten stars known to be closer to the earth; Sirius is one and it is the closest of the brightest stars and the brightest one of all.

Both orange components of 61 Cygni have the same spectral class of K5, but one is nearly a stellar magnitude brighter than the other (5.6 as against 6.4). This couple is easily resolved by school telescopes since the angular separation of the components is 27″ of arc, which corresponds to an actual distance of 82 astronomical units—somewhat less than the diameter of our planetary system. The two suns have a 720-year period of revolution round their common centre of gravity.

In recent times 61 Cygni has attracted more attention due to the fact that the brighter component was found to have an invisible companion of very small mass. The existence of a companion star was suggested to the American astronomer Strand by certain irregularities (perturbations) in the motion of the star. A. N. Deitch of Pulkovo Observatory then carried out a detailed investigation of the problem. He recently reported that the dark invisible companion of component A has a semimajor orbital axis of 2.3 astronomical units and a mass of 0.012 solar mass. A body of this mass cannot be a star in the ordinary sense of the word and should be more like Jupiter physically (the Jovian mass is about one-thousandth the solar).

In this respect, 61 Cygni is not alone: a number of other stars have been found to have dark invisible companions. It may be that in some cases the overall perturbing influence of several such satellites is viewed by astronomers as the action of a single companion star, thus obtaining an unrealistically large value of mass. If that is so, the actual masses of some dark invisible satellites of many stars are similar to the masses of the larger planets of the solar system. But then we are entitled to say that the planetary systems of other stars have already become the subject of direct (true, only "gravitational", so to say) observations.

As for the dark satellite in the 61 Cygni system, we can take it to be an "extinct" star or one with a very low light output because the orbit is extremely elongated, which is not characteristic of planets but rather typical of binary stars.

The constellation Cygnus also has two unusual variable stars. One of them was detected in 1687 by the German astronomer Kirch. It is the long-period variable Chi Cygni. At peak brightness it becomes a star of Mag. 2.3, exceeded only by Deneb and Gamma Cygni. Then the cross in Cygnus

becomes fuller, because Chi Cygni is located in the central portion of the staff. But at minimum it is beyond the range of the unaided eye. Neither can it be seen in a school telescope because Chi Cygni is then a star of Mag. 14.3. The mammoth dark red star Chi Cygni is one of the coolest stars with a surface temperature of only 1,600°. It takes Chi Cygni nearly 407 days to go through a full cycle of brightness variation. Take a look and see if this exciting star is visible in the heavens. On the same staff of the cross, near Gamma Cygni, is another peculiar star of about sixth magnitude. It is P Cygni. In 1600, the astronomer Janson noticed in this area an unknown bright star of the third magnitude. For several years its brightness continued undiminished and then began to decline. Between 1619 and 1923 this strange star was visible only in a telescope. From then on the brightness has varied irregularly between fifth and sixth magnitude, and now the star has come to a standstill in just that state.

The spectrum of P Cygni is characteristic of hot supergiants, but has many peculiarities reminiscent of the spectra of novae. According to a hypothesis of Vorontsov-Velyaminov, stars of the P Cygni type (there are about a score of them) are "unsuccessful" novae. After the outburst of 1600, P Cygni did not return to the original state as typical novae do, but got stuck somewhere at an intermediate stage. It is hard to say what its future will be, but apparently such *anomalous* novae (which is the accepted designation for stars of the P Cygni type) are in a state of unstable equilibrium. Only the future will show whether it will flare up again or, on the contrary, will fade out drastically.

AQUILA, The Eagle

Altair, or Alpha Aquilae, is a hot blue star very close to us (5 parsecs away). It is only 8 times as luminous as the sun and 2.2 times the solar diameter. Beside the giant Deneb, Altair is quite ordinary. The spectrum of Altair tells us that the intervening distance is becoming smaller at the rate of 26 km every second. And that seems to complete the picture of this very run-of-the-mill star.

Directly under Altair and closer to the horizon we see a bright Cepheid, Eta Aquilae. Its variable character was

discovered by John Goodricke's friend and neighbour Edward Pigott (1750-1807), a marvellous investigator of variable stars. The discovery was made at the end of 1783, which was one year before the discovery of Delta Cephei. Strictly speaking, it would be more appropriate to call variable stars "Aquilids" and not Cepheids, but the latter name is the historically accepted one. The variable Eta Aquilae is a very ordinary and typical Cepheid with a period of 7.18 days and brightness fluctuations between Mags. 3.7 and 4.4.

The Aquila constellation has a number of faint double stars (for instance, *h* Aquilae) but they are hardly worth discussing after the magnificent sights of the constellation Cygnus, The Swan.

HERCULES

This constellation is outstanding first of all because it contains the *apex*, or the imaginary point in the direction of which our whole solar system together with the sun is moving.

When walking through a thick forest, the trees ahead appear to move apart, those left behind on the contrary appear to come together. In the sky we have the same effect, to some extent. Of course there are no really fixed stars, everything is in motion in nature. But the motions of stars observed from the earth have a certain component produced by the motion of the sun (and hence the earth). Those stars in the sky that lie in the direction of the sun's motion appear to be moving apart, while those in the opposite direction exhibit the reverse effect. A very detailed analysis of all these phenomena has enabled us to determine the equatorial coordinates of the apex. They are

18 hours Right Ascension (α) and $+30^\circ$ Declination (δ)

A star map shows that the apex lies close to the star Nu Herculis. That is the direction in which our solar system is moving at a velocity of 20 km/s. In one day we cover about two million kilometres.

This is the motion of the sun relative to the nearest stars. Do not confuse it with the revolution of the solar system about the centre of the Galaxy, which is at a speed

of 250 km/s and, in the present epoch, is directed towards the constellation Cepheus.

The extensive constellation Hercules contains 140 naked-eye stars and has quite a number of sights. First of all, the extraordinary star Alpha Herculis. Of the bright stars, it is the largest, far superior in this respect even to Betelgeuse. Our imagination is staggered by the size of this titan: a red giant of giants 800 times the diameter of the sun.

Like Betelgeuse, Alpha Herculis is a semiregular variable star of the Mu Cephei type. Two oscillations stand out in the otherwise complicated and at first glance completely haphazard light curve. One has a long period (close to 6 years) and an amplitude of Mag. 0.5. On this are superimposed other oscillations with variable amplitudes (from Mag. 0.3 to 1.0) and periods (from 50 to 130 days). It was no easy job to untangle this mess of change.

At a distance of 4".6 from Alpha Herculis we see a yellow companion of Mag. 5.4 that completes a full circuit round the primary star in 111 years. In turn, this companion star is a spectral binary with a period close to 52 days; both stars are surrounded by an expanding shell of gas.

We have already encountered globular star clusters, but here in the Hercules constellation there are two really outstanding structures of this kind.

The brighter one is the globular cluster M13, which is easy to find in binoculars between the stars Eta and Zeta Herculis. In a three-inch telescope it breaks down round the fringes into separate stars. How beautiful are these myriad points of light scintillating round the mammoth sphere of stars (Fig. 62).

The globular cluster M13 contains about half a million stars, mainly of the later spectral classes. Unlike the galactic clusters that are mainly made up of hot giants, the brightest stars of globular star clusters (and this includes M13) are cool red giants. Hot blue stars are rarities here. Globular clusters apparently have quite a few stars that resemble our sun.

Globular clusters exhibit a large number of variable stars (M13 has about 15 variables), mainly short-period Cepheids. All globular clusters are very distant objects. For example, it takes light 23,000 years to cover the distance from us to M13.

To date about a hundred globular star clusters have

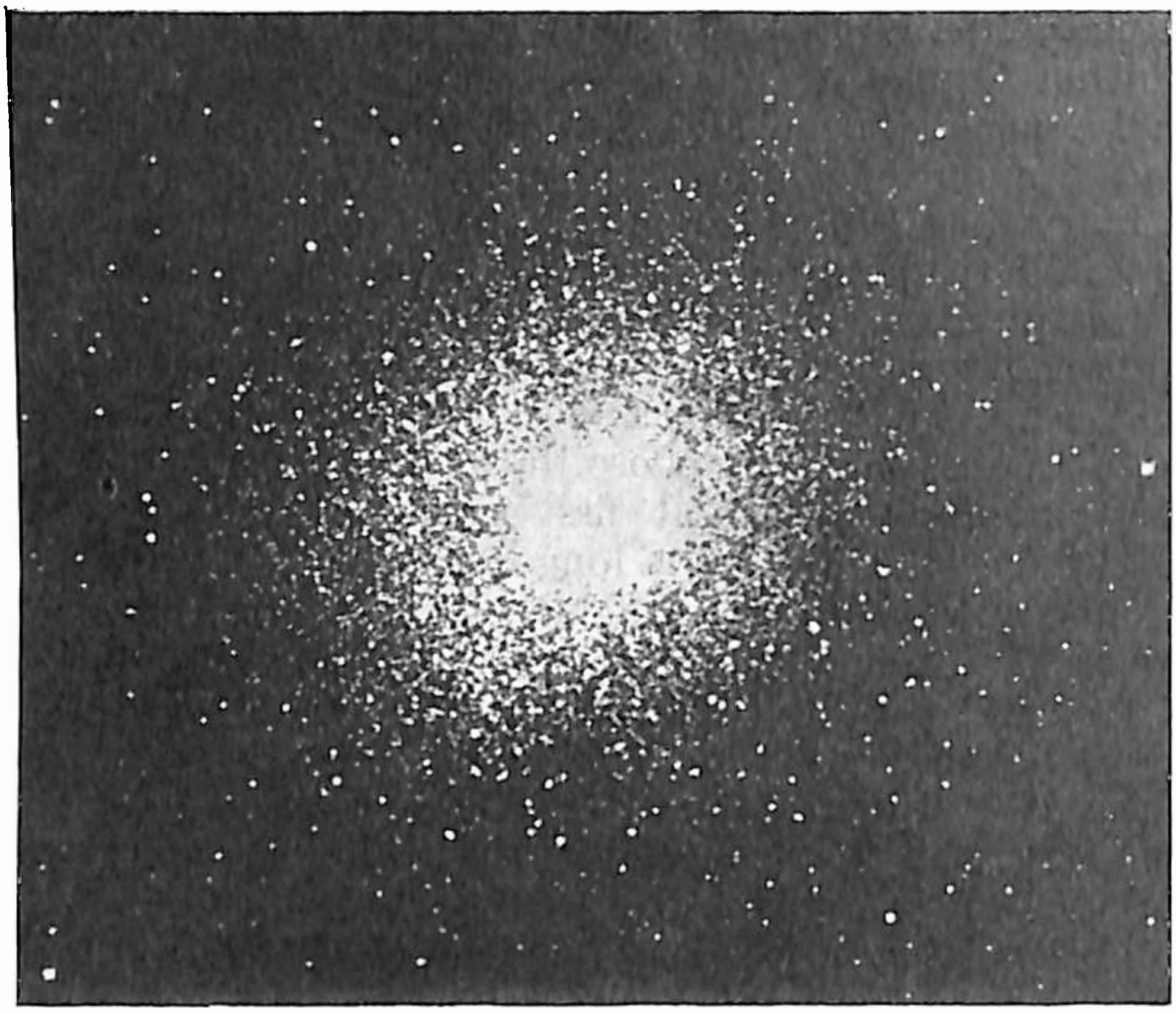


Fig. 62. The globular star cluster M13.

been recorded. In our Galaxy—apparently in other galaxies too—they form a spherical subsystem.

Globular clusters are huge agglomerations of stars measuring between 130 and 300 light years across. An interesting feature is that these spheres of stars have no dust or gaseous nebulae. But although the interstellar space there is very transparent the appearance of the sky, particularly in the central portion of a globular cluster, is enchanting. Imagine thousands of stars as bright as Venus and thousands more like Sirius covering the whole vault of the sky!

Globular clusters are very stable structures. We do not know how they originated but we can safely say that they will go on existing without any fundamental changes for many millions of millions of years!

Almost midway between the stars Iota and Eta Herculis is a second globular cluster M92. It is farther away than M13 (7.3 kiloparsecs) and is poorer in stars, but in the sky it covers a larger area (30′ of arc compared with the

21′ apparent diameter of M13). The M92 cluster is also unusual in composition with many hot giants. In fact in this respect it is a unique object.

CORONA BOREALIS, The Northern Crown

At 5 in the morning of February 9, 1946, Alexei Kamenchuk, trackman of the Amur Railway noticed an unknown star in the constellation Corona Borealis. It was even brighter than Gemma, the principal star of the constellation, and completely distorted the customary outline. This modest lover of astronomy reported his finding to the Pulkovo Observatory, and soon the news of the outburst of a nova in the constellation Corona Borealis spread round the globe.

Generally speaking, this was not an entirely new star. Exactly 80 years before, in 1866, it had flared up and since that time had been recorded in star catalogues as the recurring nova T Coronae Borealis. This star, we now know definitely, belongs to the category of so-called nova-type stars, novae in miniature, if you like. Their outbursts are physically very much like the explosions of conventional novae with the sole difference that nova-type stars have much smaller amplitudes of brightness variation (8 magnitudes as compared with the 12 magnitudes of real novae).

The prominent Soviet investigators of variables, B. Kukarkin and P. Parenago, in 1934 discovered an important relationship between the brightness amplitudes of nova-type stars and the time interval between successive outbursts. The smaller the amplitude, the more frequent the outbursts. For typical novae with a 12-magnitude amplitude of brightness fluctuation, the outbursts should repeat at intervals of only 5,000 years on an average. That is why we have never been able to observe twice the flare up of a typical nova: astronomical science is still too young.

Knowing the variations of brightness of T Coronae Borealis up to 1866, Soviet scientists predicted the next outburst (on the basis of the 8.6-magnitude amplitude) in 80 years. The discovery of A. Kamenchuk confirmed the fact that this relationship has the force of a statistical law of nature.

Between outbursts, T Coronae Borealis is a star of Mag. 11 and has a very unusual complicated spectrum: a combination of the typical class M3 spectrum and the "hot"

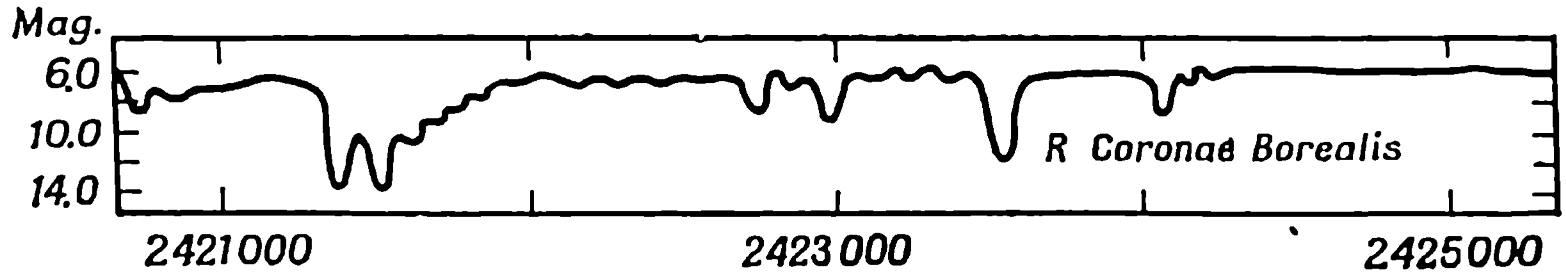


Fig. 63. The light curve of R Coronae Borealis.

spectrum B0. Apparently, T Coronae Borealis, which is 800 parsecs from the earth, is a system of two stars: a cool red giant and a hot white dwarf, the latter (judging from all the information) being the nova-type star.

The Corona Borealis constellation has yet another nova-type star with the designation R. The behaviour of this object is highly eccentric. Most of the time R Coronae Borealis may be seen as a sixth-magnitude star with very small and irregular fluctuations of brightness. But at times it suddenly and drastically fades away several stellar magnitudes (Fig. 63). There were times when R Coronae Borealis became a star of the tenth magnitude and even the fifteenth magnitude. And the star stays at minimum brightness for various periods from several months to a number of years, after which it again returns to normal. Judging from the light curve, R Coronae Borealis is a sort of nova turned inside out. Typical novae and nova-type stars flare up from time to time; the R Coronae Borealis type of star, on the contrary, exhibits recurring decreases of brightness. At minimum, these stars have spectra with bright emission lines, and this gives us the right to place them in the category of nova-type stars.

Stars of the R Coronae Borealis type have unusual atmospheres consisting mainly of carbon atoms. Some of these stars have spectra that put them in the rare spectral class R. Perhaps the R Coronae Borealis stars diminish in brightness because of occasional blurring of their atmospheres due to unknown causes. At any rate they are such unusual stars that the reader will undoubtedly want to find time and take a look to find out what the brightness of R Coronae Borealis is today.

Let us take a look at two more stars. Gemma, an enormous hot blue star, that careful studies have shown to be

an eclipsing variable and a spectral binary with a period of about 17 days and an amplitude of Mag. 0.1.

Another interesting object is the barely distinguishable naked-eye double star Sigma (σ) Coronae Borealis. It consists of two stars separated by 6″.6 of arc. This system has a very elongated orbit (eccentricity 0.78) with a period of 1,000 days. The brighter component, Class F8, is in turn a spectral binary with a period of only 1.14 days. Thus, strictly speaking, the tiny star Sigma Coronae Borealis is a very curious triple star.

EQUULEUS, The Little Horse

This constellation and Caelum are the two smallest constellations in the whole sky. Together they have only a score of naked-eye stars. But The Little Horse has a very curious triple star Epsilon Equulei. At a distance of about 11″ from the primary fifth-magnitude star is a companion of the seventh magnitude. The brighter component is in turn a binary, and a very close one that only the biggest telescopes are capable of separating. The orbit of this star is extremely elongated (having an eccentricity of 0.70), and the circuit round the common centre of gravity takes 101 days.

So you see, multiple systems are rather common objects in the stellar skies. Their large numbers argue in support of the joint, group, generation of the stars, since it is impossible to account for multiple systems by the "capture" of stars in accidental encounters.

DELPHINUS, The Dolphin

Train your telescope on Gamma Delphini. This is a double star, the principal component of which is an exact copy of our sun. At a distance of about 10″ of arc from the primary yellow star of Mag. 4.5 we see a companion star (Mag. 5.5) somewhat hotter and greenish in appearance. This is undoubtedly a pure binary, but the period of revolution is very great, probably amounting to several thousand years. Pay special attention to the primary star, the yellow one. From this star (perhaps from one of its planets, who knows) our sun looks just the same.

SAGITTA, The Arrow

There are no objects of interest in this tiny constellation, if we discount the Cepheid S Sagittae, whose brightness changes in 8.38 days from Mag. 5.8 to 7.0 and back again.

VULPECULA, The Fox

Planetary nebulae do not always resemble the discs of planets. It is rather the exception than the rule. Planetary

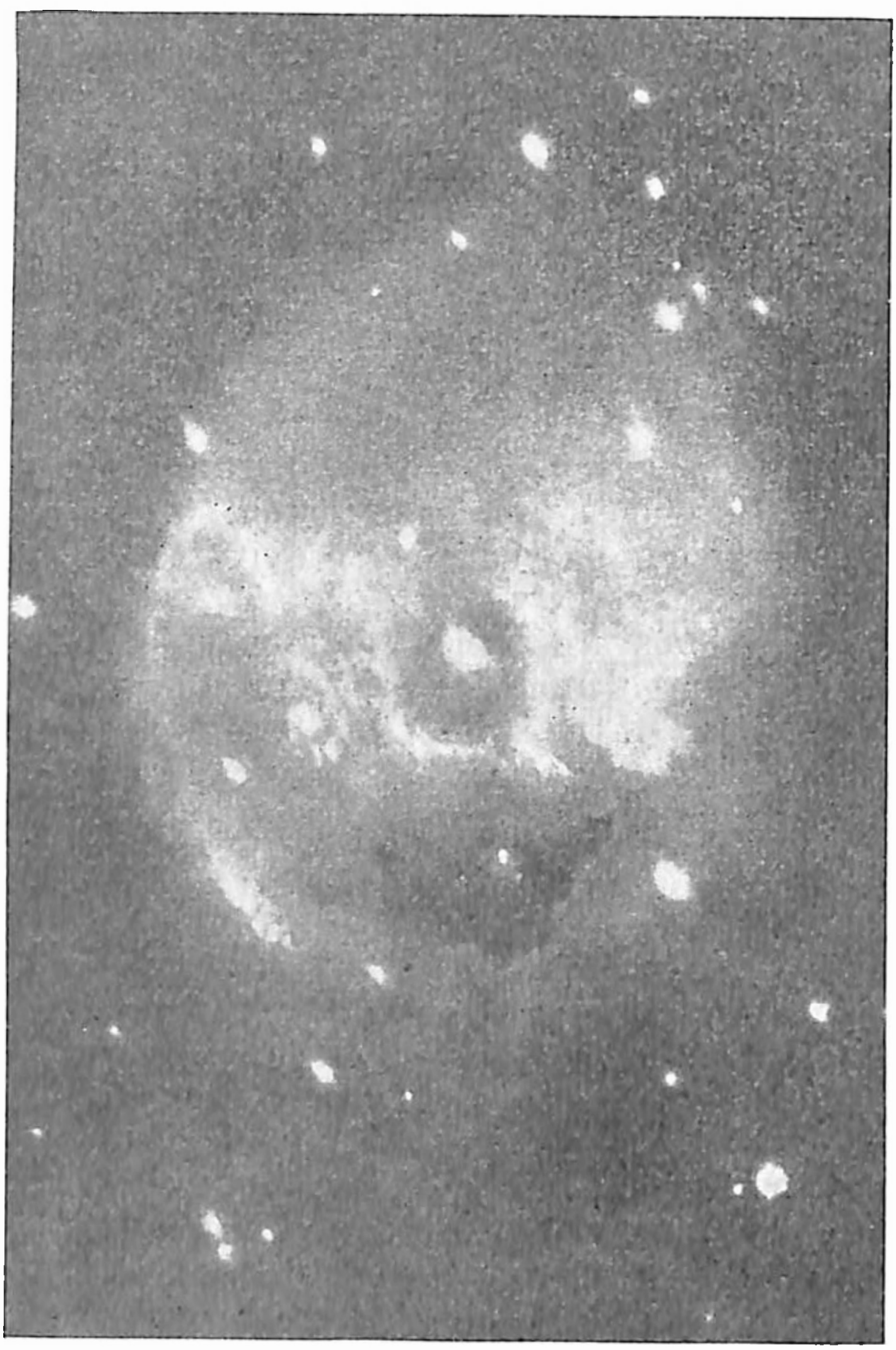


Fig. 64. The planetary nebula in the constellation Vulpecula.

nebulae come in a great variety and complexity of forms, at least, outwardly.

In the constellation Vulpecula there is a bright large (apparent size 8′ by 4′) planetary nebula of a very fanciful shape (Fig. 64). It was first discovered by Messier in 1764 and recorded in his catalogue under number 27. In binoculars the nebula appears quite clearly outlined, and in school telescopes it is possible to discern some definite shape.

Like other planetary nebulae, it is lighted up by a centrally located hot star with a surface temperature of 100,000°! The reader probably remembers from the planetary nebula of Lyra that the "lighting-up" mechanism consists in luminescence of the atoms of the nebula due to ultraviolet emissions of the central star.

The nebula in Vulpecula is a rather distant object—300 parsecs away—with a mean diameter of 240,000 astronomical units.

We repeat that the origin of planetary nebulae still remains a mystery. Various hypotheses that regard these nebulae as resulting from the ejection of gases from the atmospheres of the central stars encounter considerable difficulties. The Soviet astronomer G. A. Gurzadyan has advanced a hypothesis which considers planetary nebulae as the remnants of primitive "pre-stellar" matter that went to form the central star. The future will show just how close this comes to reality.

Like Sagitta, Vulpecula has a relatively bright Cepheid T Vulpeculae, which varies in brightness between Mags. 5.9 and 6.8 and back again in 4.44 days.

SCUTUM, The Shield

This minute constellation with its 20 naked-eye stars lies in the midst of the Milky Way, if we may say so. Right here in Scutum, on a dark clear night we see a bright star cloud (Fig. 65), one of the many components of the Milky Way. It is particularly prominent in the southern regions of the Soviet Union.

The constellation Scutum will be seen to have two bright open star clusters. The first one is located alongside the long-period variable R Scuti, has a diameter of 12′ of arc and contains about 200 stars, mainly white giants

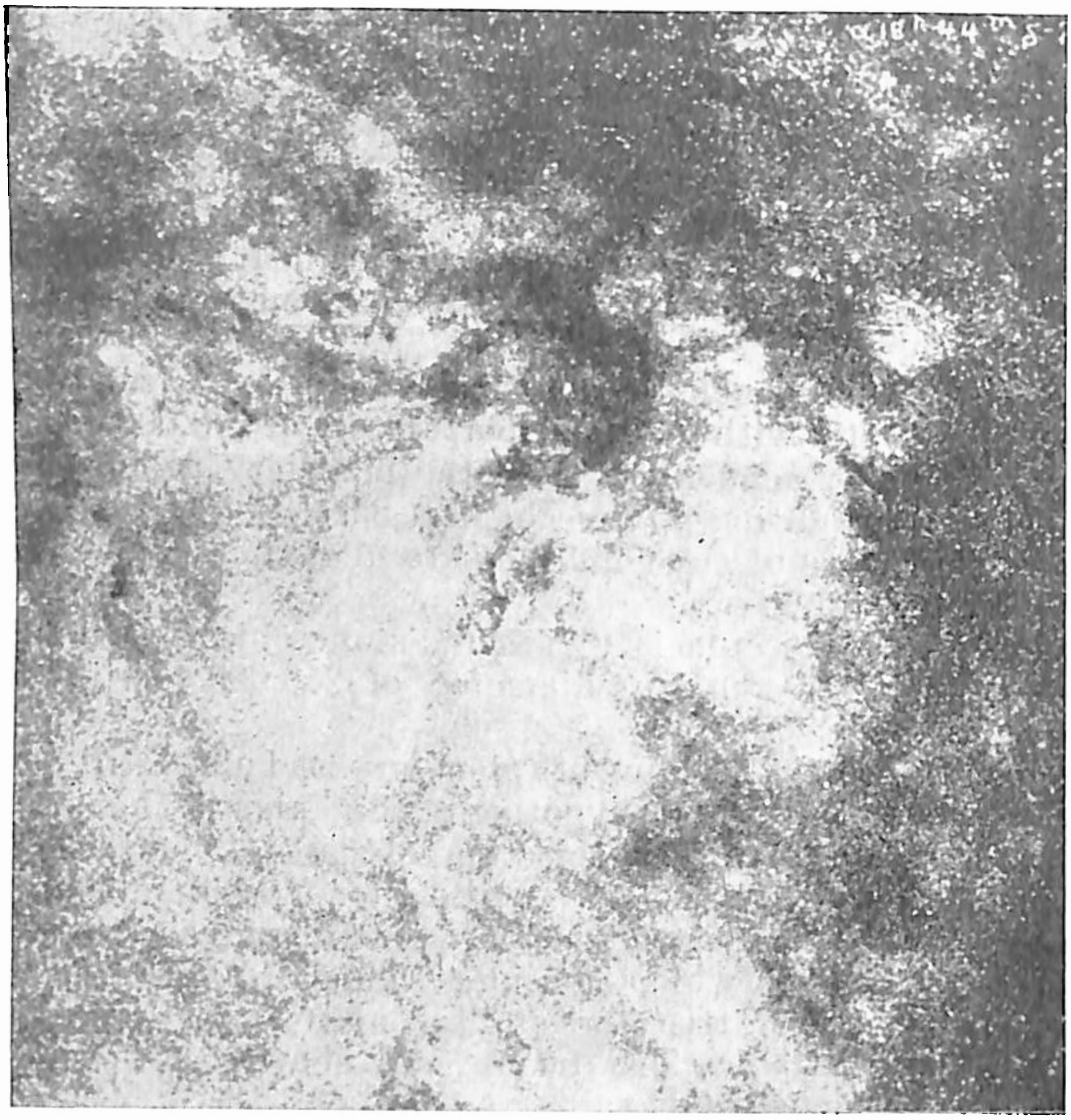


Fig. 65. The star cloud in the constellation Scutum.

with a slight admixture of stars of the later spectral classes. The cluster has a true diameter of 5.5 parsecs and lies at a distance of 1,600 parsecs.

To the south, in the opposite corner of the constellation lies a somewhat fainter cluster made up of 75 stars and occupying a volume 6.6 parsecs across. This is one of the most distant clusters, it is 2,300 parsecs away.

SERPENS, The Serpent

We have mentioned elsewhere that the constellation Serpens consists of two disjointed parts. The western part is called Serpens Caput (the Serpent's Head) because pic-

torial star maps depict this portion; the eastern "piece" is Serpens Cauda (the Serpent's Tail).

In the constellation Serpens note first of all two double stars. The Serpent's Tail has a star, Delta Serpentis, resolvable in school telescopes into two yellowish stars of Mags. 4.2 and 5.2, separated by 4″ of arc. This is a physically related pair, a true binary, with a very big period of revolution of apparently many hundreds of years.

The Serpent's Head also has a beautiful double star, Theta Serpentis. The two yellow-greenish stars of Mags. 4.5 and 5, separated by 21″ of arc, resemble the vicious eyes of a serpent. Although there is a tremendous distance between the component stars, their proper motions are definitely related, indicating a physically unified system.

By now the reader has seen no small number of globular star clusters, but still the "sphere of stars" M5, which lies in the tail of the serpent, is something to see. It is a very bright swarm of stars and beautiful even in binoculars. In school telescopes, we can already see separate stars round the fringes. Physically, the globular cluster in Serpens is much like the stellar sphere in Hercules (M13). M5 is 8.3 kiloparsecs away and contains approximately 60,000 stars.

Serpens also has a bright diffuse nebula, M16. It lies in the head of the serpent on the southern boundary of the constellation. In the sky it occupies about the same area as the moon's disc and is distant 1,400 parsecs. The luminosity of the nebula is due to the superhot class O star within it.

OPHIUCHUS, The Snake-Strangler

In the extensive constellation Ophiuchus, try to find a little star (Mag. 9.7) studied by the noted American astronomer Barnard (for Epoch 1900 its Right Ascension is 17h 52 m.9 and Declination $+4° 25'$). This is no fixed star even in a figurative sense. "The flying star of Barnard", as astronomers sometimes call it, has an unusually high rate of proper motion. In one year it covers 10″.27 of arc on the celestial sphere, and in 188 years it shifts its position by an amount equal to the moon's disc. If all the stars were so restless, the configurations of the constellations would change within a few generations.

Barnard's star is a cool red dwarf that emits 2,500 times less light than the sun. It is precisely for this reason that Barnard's star, though close to the earth (only 1.8 parsecs distant), is lost among the great multitude of faint ninth- and tenth-magnitude stars. But if you succeed in locating it, only a few years of observations will demonstrate its actual motion in space!

The star 70 Ophiuchi is a well-studied binary. Two orange stars of Mags. 4.2 and 5.9, separated at the present time by an interval of 4″.6 of arc, are in constant revolution about a common centre of gravity with a period of 87.85 years. The more massive star has 89% solar mass, that of the other component is somewhat less massive (72% solar mass). The orbit is rather elongated (eccentricity 0.50) and the two suns are comparatively close to the earth (at a distance of 5.4 parsecs).

The constellation Ophiuchus has four bright globular star clusters united in two couples. The first lies in the middle of the constellation, somewhat below the celestial equator (M12 and M10). They are 5.8 and 5.0 kiloparsecs distant, respectively. They both contain roughly the same number of stars, but the M12 cluster has more hot stars than does the M10 cluster.

The other two "stellar spheres" may be found close to the southern boundary of the constellation (M62 and M19). They are both at the same distance from the earth (6.9 kiloparsecs), but M19 has more stars. The M62 cluster has fewer stars and they are somewhat cooler. This is a rather rare instance of a double globular cluster, a sort of analogue of a double (binary) star.

To the north of the star 70 Ophiuchi is a planetary nebula NGC 6572. It is rather small (9,000 astronomical units across, which is 27 times less than the diameter of the Vulpecula Nebula) and is not so bright as other familiar planetary nebulae. It takes light 4,000 years to bring information to us about this distant and rather ordinary object.

AQUARIUS, The Water Bearer

The star Zeta Aquarii was first separated into two components in 1777. Since then astronomers have discovered orbital motion with a period (according to the latest findings) of 361 years. Both components are yellowish stars

of Mags. 4.4 and 4.6 separated at the present time by only 2″ of arc. For school telescopes this is definitely a very difficult object.

But the observer will be rewarded by another object in the Aquarius constellation. This is the unique planetary nebula NGC 7293 (located near Upsilon Aquarii). It is the brightest and largest planetary nebula in the skies. What is more, it fully justifies its name, for in a telescope one can see a bright and slightly flattened disc. The nebula has apparent dimensions of 15′ by 12′. The true mean diameter is close to 300,000 astronomical units, which is considerably in excess of the dimensions of all other known planetary nebulae.

This mammoth nebula is lighted up by an absolutely exceptional star—the hottest of all known stars with a surface temperature equal to 130,000°! We are 180 parsecs away from this heat.

Messier's catalogue records under number 2 a bright globular cluster, which, like the nebula NGC 7293, is one of the chief sights of the constellation Aquarius. It is very bright, very large (apparent diameter: 17′) and consists mainly of comparatively hot stars. In a number of stars it even exceeds the famous cluster in Hercules (M13), but it is not so impressive due to its great distance of 15.8 kiloparsecs.

CAPRICORNUS, The Sea Goat

This otherwise commonplace configuration has two bright stars of interest, Alpha and Beta Capricorni. Turn your binoculars on one of them and you will see that it is a double star. An optical double. The component stars (Alpha$_1$ and Alpha$_2$) are in no way related physically and are slowly moving apart. The only consolation is that each one of them is separately a real pure binary star. Both pairs, however, are so closely connected that no school telescope is capable of resolving them.

After the bright globular cluster M2, the stellar swarm in Capricornus (M30), near Zeta Capricorni, will not surprise the observer. It is smaller, not so brilliant; although, like M2, it consists of comparatively hot stars. It is 12.6 kiloparsecs distant and is coming closer at the rate of 100 kilometres every second; so says the shift of spectral lines.

We may remark at this point that the motions of globular clusters have not been studied very thoroughly, and the line-of-sight velocities of these objects reflect both their own "proper" velocities and also the velocity of our earth in its complicated flight round the centre of the Galaxy.

SAGITTARIUS, The Archer

While observing galaxies that are similar in structure to our own stellar system, we see that there are much larger numbers of stars per unit volume in the central regions than on the outskirts. To illustrate, look at the photograph of the Andromeda Nebula on page 100. In the centre of this galaxy is a prominent dense and spherical stellar nucleus. There are so many stars here and they are so densely packed together that it was only in 1944 that the American astronomer Baade first succeeded in resolving the nucleus of the Andromeda Nebula into separate stars.

There can be no doubt that our Galaxy too has a similar star-like nucleus. We can calculate from stellar velocities (directions and magnitudes) where this galactic nucleus should be located on the celestial sphere. Here is what has been found: the approximate equatorial coordinates of the galactic centre are:

Right Ascension: 17h 38m; Declination: —30°
(Epoch, 1900)

A star map shows this point to be located in the constellation Sagittarius. (An extended object, the nucleus of the Galaxy reaches over into the constellations Scutum, Scorpio, and Ophiuchus as well.) Yes, here in Sagittarius is the magnificent nucleus of the Galaxy, the massive assemblage of stars whose combined attraction compels all the other stars of the Galaxy to revolve about them. Naturally, the stars of the nucleus are also in revolution about this mathematical point—the common centre of gravity of our whole stellar system. It was recently established that the dynamic centres of our Galaxy and the Andromeda Nebula (and possibly other stellar systems as well) are distinguished by strange small-size objects (with diameters of the order of 20 parsecs), apparently extremely dense

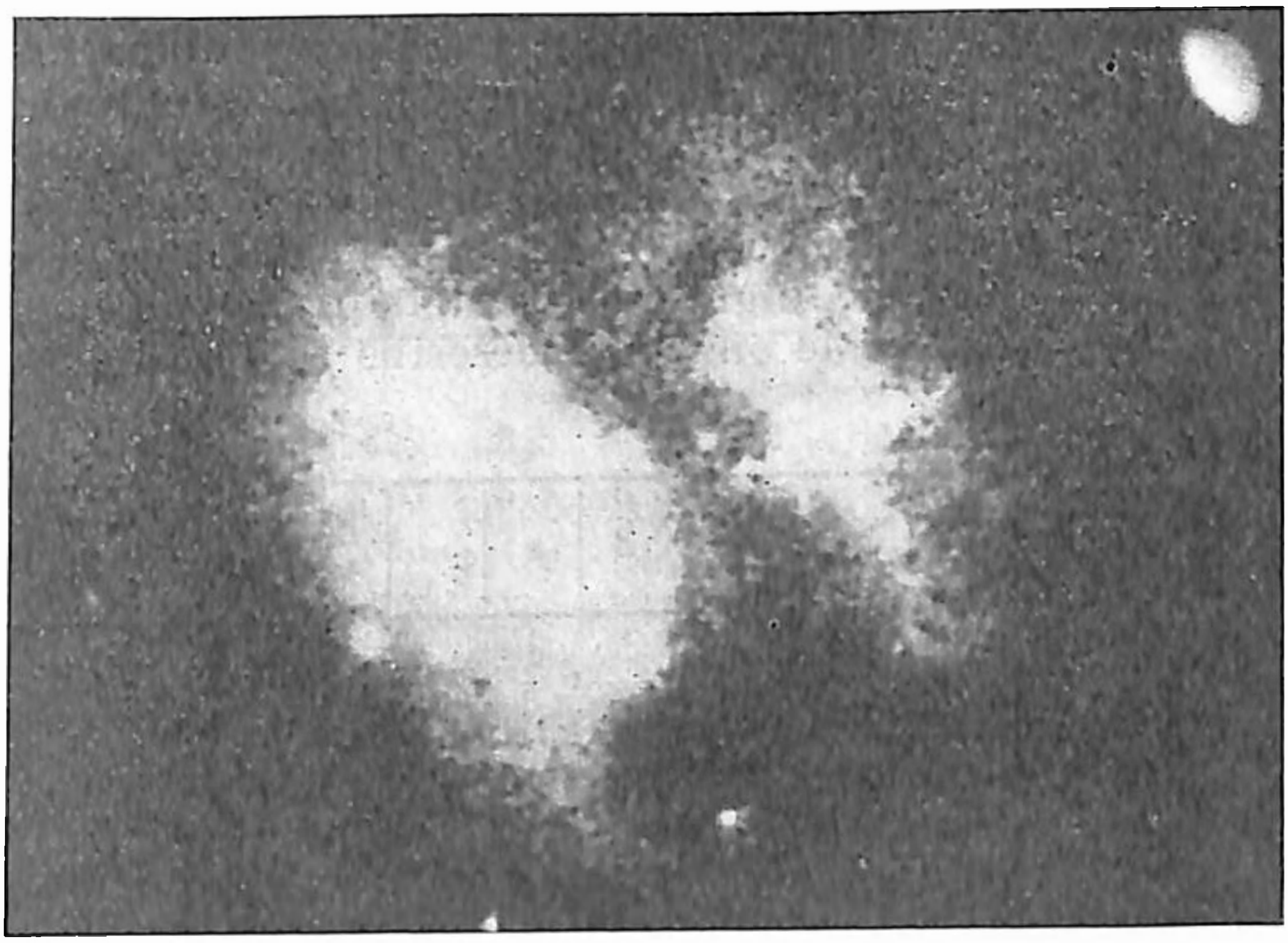


Fig. 66. Infrared-ray photograph of part of the galactic nucleus.

globular formations that are powerful sources of radio emission.

Unfortunately, none of this is visible even in the most powerful of modern optical telescopes. The galactic nucleus is enveloped by extremely thick clouds of dark dust that blocks visible rays. But this same cosmic dust freely passes the invisible infrared rays and radio waves. This has enabled astronomers to photograph in infrared rays a part of the galactic nucleus (Fig. 66) and also to study the nucleus with the facilities of radio astronomy.

Still, it is very interesting to find in the sky the brightest and most "stellar" portion of our Galaxy hidden by a dark cosmic dust shroud. If interstellar space were perfectly transparent, we would not have to explain where the galactic nucleus is located, it would be the most brilliant object in the heavens after the sun and moon. The enormous and very bright "stellar spot" in the constellation Sagittarius would reign supreme. It would cover an area in the sky hundreds of times greater than the apparent area of the full moon. Objects here on the earth would cast shadows due to the light shed by the galactic nucleus.

Nature has deprived us of this magnificent sight. Still and all, the constellation Sagittarius is extremely rich in star clusters and nebulae well within the range of general observation. Let us look into this matter.

It would be tiresome indeed to describe in detail each one of the ten bright star clusters of Sagittarius. Let us list them in a table and then describe the most interesting objects.

NGC	M	α_{1900}	δ_{1900}	d	m	N	r, kilo-parsec	D, parsec	Sp	Type
		hr min			Mag.					
6494	23	17 51.0	—19°00′	35′	6.0	120	0.6	6.0	B9	Open
6520	—	17 57.1	—27 54	5	7.5	25	0.7	1.0	—	Ditto
6531	21	17 58.6	—22 30	12	7.0	35	1.5	5.1	B0	Ditto
6603	24	18 12.7	—18 39	4	11	50	5.0	5.8	—	Ditto
6611	16	18 13.2	—13 49	25	6.6	55	1.7	12.0	—	Ditto
6121	4	16 17.5	—26 17	26	4.4	—	2.3	15		Globular
6626	28	18 22.7	+6 30	15	8.5	—	4.6	—		Ditto
6656	22	18 30.3	—24 00	35	6.5	—	3.0	25	—	Ditto
6723	—	18 52.8	—36 46	13	7.7	—	10.0	—	—	Ditto
6809	55	19 33.7	—31 10	29	7.1		5.8	45		Ditto

The first two columns give the designations in NGC and Messier's catalogue. The next two indicate the equatorial coordinates of the cluster for the Epoch 1900. Then comes the diameter of the cluster (d) in minutes of arc, its integrated photographic brightness (m), the number of component stars (N), the distance (r) in kiloparsecs, the diameter (D) in parsecs, the integrated spectrum (Sp) and, finally, the type of cluster.

The most remarkable of the open clusters is M23. Among the globular clusters, of particular interest is the brightest of all, M4. True, in middle latitudes M4 is hard to observe because it is just above the horizon, but in the south of the Soviet Union this is a marvellous object. Another feature of the M4 cluster is that it is the closest of all globular clusters.

The globular cluster M22 is distinguished for its large number of stars (about 7 million). It is 14 times more populous than the globular cluster in Hercules (M13).

Sagittarius has three large bright diffuse nebulae. All pertinent information about these three objects is tabulated below:

M	α_{1900}	δ_{1900}	Dimensions	m	m_*	Sp_*	D, parsec	Name
	hr min							
20	17 56.3	—23°02′	27′×29′	8.5	6.9	O6	670	Triple
8	17 58.0	—24 23	35 ×60	5.8	6.8	O5s	770	Lagoon
17	18 15.0	—16 13	37 ×46	7	8.9	AOs	1,000	Omega

The letter m stands for the integrated photographic brightness of the nebula, m_* is the brilliance of the "illuminating" star of the nebula, and Sp_* is its spectrum.

Nebulae are usually named on the basis of shape and appearance, but this is often quite arbitrary.

The constellation Sagittarius contains two T associations. The first is an aggregate of stars in the vicinity of nebula M8, the second, in the neighbourhood of nebula M20. These two associations are about equally distant from the earth, 1.3 and 1.4 kiloparsecs, respectively.

SCORPIO, The Scorpion

The reader may not know that the planet Mars has a competitor in the sky, at least that is what those thought who named the principal star of Scorpio Antares (Ares is the Greek name for Mars). This bright star (Mag. 1.2) is indeed much like Mars in colour. But Mars, like all other planets, shines with an even calm light, while Antares twinkles, the more so because it is close to the horizon, which is another reason for its red colour.

Antares is a red giant somewhat hotter than Betelgeuse, radiating the combined light of 700 of our suns. It takes light nearly 173 years to cover the distance that separates us from Antares.

At a distance of 2″.9 from Antares is a companion, a blue star of Mag. 6.5 that emits 17 times more light than our sun. It is no easy job to find Antares' companion in the bright rays of the primary star.

Scorpio is a constellation in which new stars (novae) frequently burst forth. One of them, which flared up in 134 B.C., caused the famous ancient Greek astronomer Hipparchus to make a list of the stars. This was the first star catalogue in Europe. In those days, nova outbursts were philosophically important, if we may say so, for they engendered doubt in the false and preconceived idea of the immutability of the "heavens".

Scorpio has a very large number of different variable stars too. We draw attention to only one, the eclipsing variable Mu Scorpii. Judging from the light curve, this star consists of two hot giant ellipsoidal components (with spectra B3 and B6, respectively) revolving about a common centre of gravity in 1.45 days. During one cycle the brightness of the star varies from Mag. 3.00 to Mag. 3.31 and has a secondary minimum of Mag. 3.20.

The system Beta Scorpii consists of four stars. At a distance of 13″.7 of arc from the primary hot white star (Mag. 2.6) we can find a magnitude 5.1 companion star which is just as hot. Beta Scorpii is also a spectroscopic binary with a period of 6.8 days. Finally, at a distance of 0″.8 it has another, fourth, companion of Mag. 9.7. We have frequently encountered multiple stars and it might be in place at this point to say that double and multiple stars are apparently the rule and that single stars are the exception.

Like Sagittarius, the constellation Scorpio is very rich in star clusters. Six of the brightest are tabulated below with their principal characteristics:

NGC	M	α_{1900}	δ_{1900}	d	m	N	r, kiloparsec	D, parsec	Sp	Type
		hr min								
6231	—	16 47.0	—41°38′	22′	6	40	1.3	8.4		Open
6242	—	16 48.8	—39 20	10	7	44	0.6	1.8		Ditto
6405	6	17 33.5	—32 09	55	4.6	80	0.4	6.4	B5	Ditto
6416	—	17 37.8	—32 18	20	7	35	0.6	3.6		Ditto
6475	7	17 47.3	—35 47	70	3.5	80	0.25	5.3	B5	Ditto
6093	—	16 11.1	—22 44	7	8.4	—	11.0	—	K0	Globular

A glance at this table will suggest for observation two remarkable open clusters, M7 and M6. In integrated brightness the former is second only to the Pleiades. This is one of the closest and brightest open clusters. The latter one (M6) is somewhat more distant and therefore fainter, although they both have about the same number of stars.

The star Zeta Scorpii is the brightest of all known stars. We do not mean apparent brightness (it has magnitude 3.7) but luminosity: it radiates nearly 400,000 times more light than our sun! Sad to say, in the USSR it is visible only in the southern regions because of a large south declination ($\delta = -42° \ 12'$).

Of all the constellations that we have discussed, Scorpio is the southernmost. Its southern boundary is 45° from the celestial equator, which makes the constellation visible only partly in the mid-latitudes of the Soviet Union. This brings us to the limit of constellations in the southern hemisphere observable from the territory of the USSR.

THE NIGHT SKY OF ANTARCTICA

We shall not give a detailed description of the southern sky because our book is for the northern hemisphere of the earth. But more and more people are travelling to southern countries and it may be of interest and use to take a closer glance at the night sky of the southern hemisphere.

Let us imagine ourselves in the centre of the cold Antarctic continent, at the point where the imaginary terrestrial axis pierces the surface of the earth and moves out into the star-studded skies to infinity.

This axis does not encounter a single notable star that would come anywhere near Polaris in brightness. The southern polar region is extremely poor in bright stars. This is the constellation Octans. It is rather extensive but has only three stars brighter than fifth magnitude. They are all quite a distance from the celestial pole. The part of pole star in the southern skies is played by the barely distinguishable sixth-magnitude star Sigma Octantis, which is 54′ from the pole. Of all naked-eye stars, Sigma Octantis is closest to the south celestial pole. But it is so faint that it could never have played the part Polaris does for voyagers in the northern hemisphere of the earth.

The sky viewed from the south pole exhibits five new bright stars. The brightest is second only to Sirius. This is Canopus, the chief star in the constellation Carina. Despite its great distance from the earth (Canopus is 180 light years away), Alpha Carinae competes successfully with Sirius, reaching Mag. —0.9. Canopus is a yellow supergiant with a surface temperature of 7,600°. It is 85 times the diameter of the sun and has a luminosity 1,900 times solar luminosity.

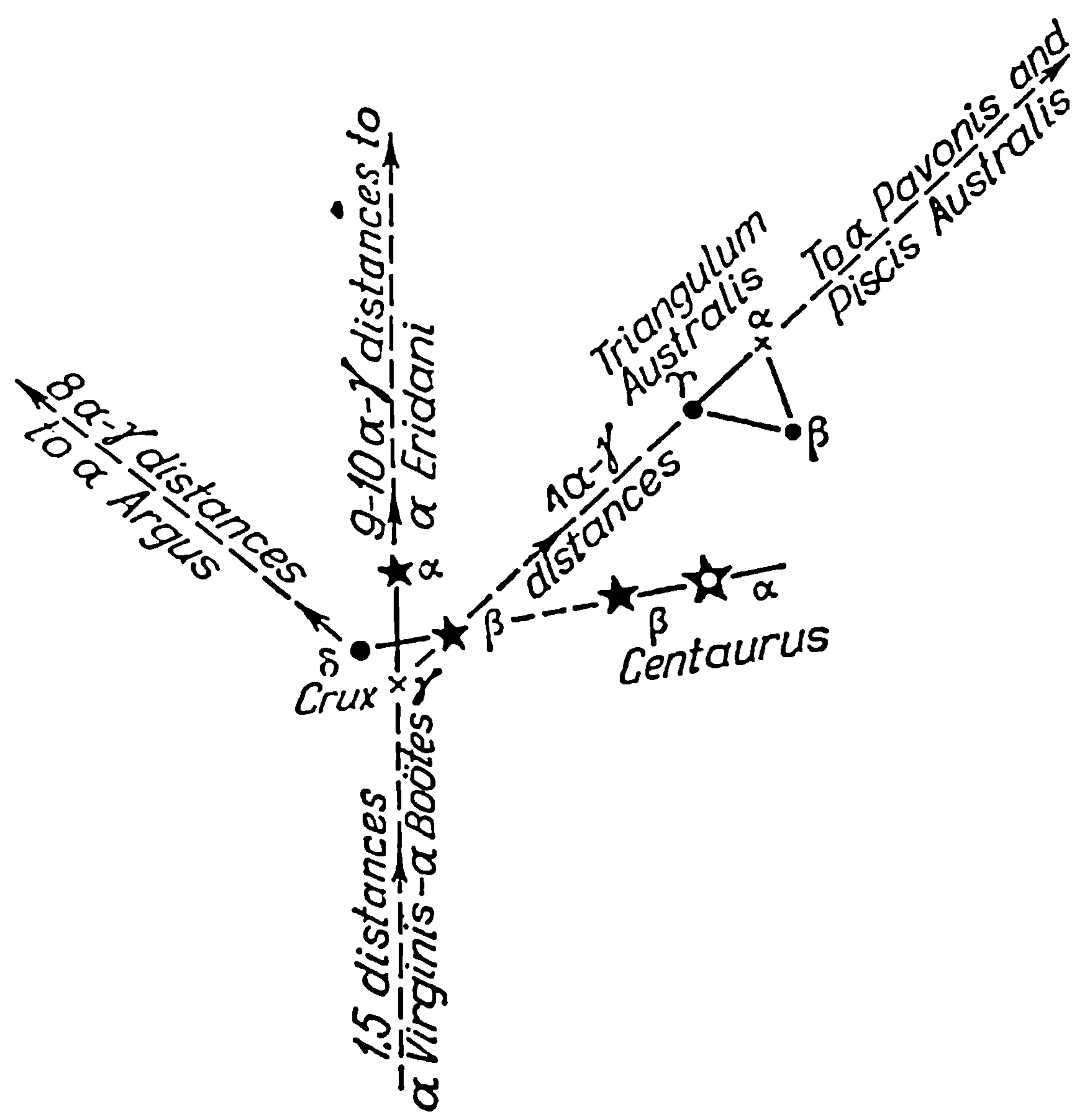


Fig. 67.

Another outstanding star is Achernar, principal star of the familiar constellation Eridanus. This is a white supergiant with a surface temperature of 15,600° that radiates 800 times more light than the sun and is 3.4 times the solar diameter. Such are the physical characteristics of Achernar. It has a magnitude of 0.6 and is 43.5 parsecs distant from the earth.

The three other bright stars are located in the same neighbourhood: Alpha Centauri, Beta Centauri, and Alpha Crucis. Their magnitudes are, respectively, 0.3, 0.9 and 1.4, making Alpha Centauri the third brightest star in the whole sky (after Sirius and Canopus).

Beta Centauri and Alpha Crucis are rather similar. They are very hot white supergiants with surface temperatures of 22,500° radiating 800 and 900 times more light than our sun. They are, respectively, 62.5 and 67 parsecs distant.

At an altitude of 30° we see another bright star that can also be seen by observers in the northern hemisphere of the earth. This is Fomalhaut, or Alpha Piscis Australis, which is visible on summer nights low on the southern

horizon in the northern hemisphere. There is nothing exceptional about this star; it is a blue star of moderate size similar, physically, to Sirius or Altair. It is only 11 times more luminous and 3.2 greater in diameter than our sun. Fomalhaut is one of the closest stars, being only 70 parsecs distant.

A close look at the star map of the southern sky (see Appendix) does not reveal any expressive patterns among the southern constellations. The prettiest one is the famous constellation Crux. The name was given by contemporaries of Magellan (16th century). The four brightest stars (Alpha, Beta, Gamma, and Delta) suggest the points of an imaginary celestial cross.

Nearby is the constellation Centaurus with its characteristic triangle of bright stars (Alpha, Beta, Epsilon). The constellations of Carina, Puppis, and Vela, which were once combined in the single constellation Argo Navis, have a large number of bright stars randomly strewn about that do not bear any resemblance at all to the silhouette of a ship of old. Still less appropriate are the names of the remaining new constellations of the southern skies, Chamaeleon, Pictor, and others.

A telescopic search of the Antarctic sky will reveal a large number of double stars, multiple stars, star clusters and nebulae. Let us take only the most outstanding or really unique objects.

The chief sight of the Antarctic sky is undoubtedly Alpha Centauri, the closest of all stars. Every devotee of astronomy covets the sight of this closest sun. Though few have the opportunity to see it, a few details about the famous star are well worth knowing.

Alpha Centauri is a triple star. The primary is a yellow star very much like our sun and at a separation of 17″.7 has a very bright orange companion of Mag. 1.7. The companion star is one-third as luminous as our sun and its surface temperature is only 4,400°. In mass and size, both stars are very similar to the sun; their period of revolution is close to 80 years. The third component of this triple system is the star Proxima (which means closest) Centauri. It is 2,400 astronomical units closer to us than the principal yellow star.

Proxima Centauri is a cool red dwarf that emits 20,000 times less light than does our sun. The angular distance

Fig. 68. The Large Magellanic Cloud·

between Proxima and the chief components of Alpha Centauri is very great, approximately four apparent lunar diameters. If Proxima were replaced even by such an ordinary star as our sun, Alpha Centauri would become one of the most beautiful triple stars in the terrestrial sky. But Proxima is a red star of the eleventh magnitude and is quite lost in the multitude of other telescopic stars. The period of revolution of Proxima about the common centre of gravity of the system is very great, not less than several thousands of years.

The constellation Carina has two very bright and open star clusters located close to the earth. Their coordinates for Epoch 1900 are:

Right Ascension: 9h 59m.5; Declination: —59°38′ and
Right Ascension: 10h 02m.2; Declination: —58°08′

The first consists of 160 stars, the second, 130. Both are at a distance of 400 parsecs from the earth.

Very impressive are two globular star clusters 47 Tucanae and Omega Centauri. They have integrated brightness close to fifth magnitude, while their apparent diameters are, respectively, 54′ and 65′, which are considerably in excess of the angular diameters of all other globular star clusters. They are 5.8 and 5.0 parsecs away, respectively.

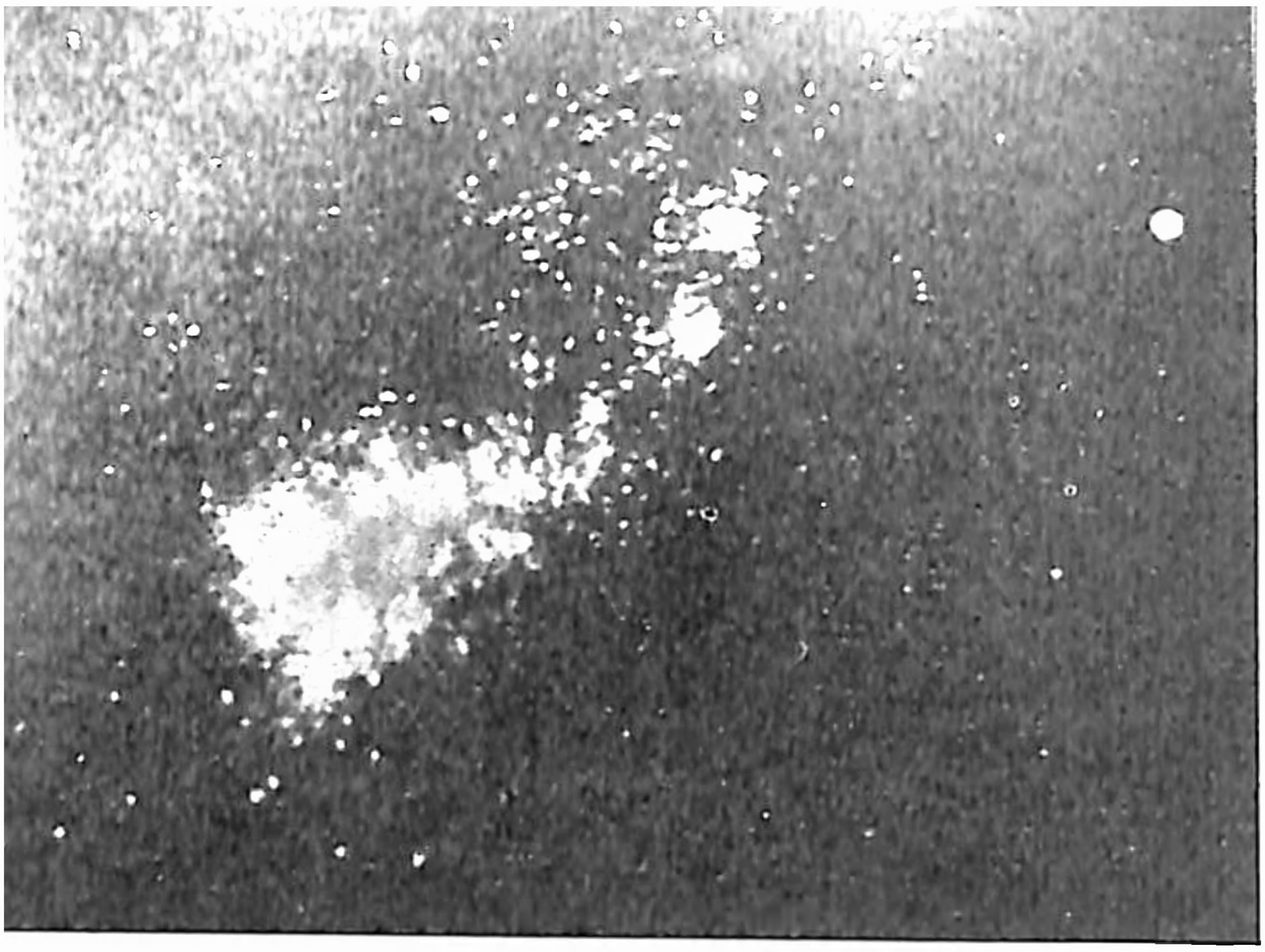


Fig. 69. The Small Magellanic Cloud.

The 47 Tucanae cluster is the most populous of the known globular clusters, combining tens of millions of stars!

Unmatched anywhere else in the sky are the famous Magellanic Clouds: the Large Magellanic Cloud and the Small Magellanic Cloud. The former is seen in the constellation Dorado, the latter in the constellation Tucana. On a dark starry night they are indeed like some kind of strange glowing fixed clouds. But in a half hour of viewing you will see that they are in motion together with the whole celestial sphere and their relative positions to the stars remain unchanged, which is an important sign of their cosmic nature.

The Large Magellanic Cloud (Fig. 68), is reminiscent of the Segner wheel of schooldays, the Small Magellanic Cloud looks like a boxer's punching bag (Fig. 69). The Magellanic Clouds occupy a large area in the sky. The Large Cloud is 12° across, or 24 times the diameter of the moon's disc. The Small Cloud is 8° in diameter.

The Magellanic Clouds were first described by a companion of Magellan and his biographer Pigafetta. Observers always remark on the similarity of the Magellanic Clouds

with our Milky Way. The Clouds appear to be pieces torn off the Milky Way.

There is more than just this superficial similarity. Telescopic observations reveal the stellar nature of these remarkable structures. They are enormous stellar systems, the closest of their kind to us, and companions of our own Galaxy. They consist of many tens of millions of stars, including over 2,000 known variables, several tens of star clusters and nebulae. Light takes nearly 125,000 years to come from the Magellanic Clouds but their centres are separated by half that distance.

In actual size, the Magellanic Clouds fall far short of our Galaxy and the Andromeda Nebula. Still, the Large Cloud is about 20,000 light years in diameter and the Small Cloud is close to 17,000 light years across. The Large Magellanic Cloud is comparable to the M33 galaxy of the constellation Triangulum (9 kiloparsecs in diameter); if they weren't so close to our Galaxy, both clouds might be regarded as quite independent star systems.

Some of the objects of the southern celestial hemisphere are not at all visible in the latitudes of the Soviet Union. Unfortunately, they include the Magellanic Clouds, Alpha Centauri and nearly all the other sights we have just mentioned. But Canopus can be seen in the extreme south (south of latitude 38°) on winter nights low on the horizon.

To some it may be of sporting interest to get a glimpse of a few of the typically southern constellations. At Moscow's latitude, one can see portions of the following constellations low on the horizon:

Piscis Australis (with Fomalhaut), Sculptor, and Fornax on autumn evenings;

Caelum, Columba, Puppis, and Pyxis on winter evenings;

Antlia, Centaurus, and Lupus on spring evenings;

Microscopium on summer evenings.

On the other hand, it is interesting to note that from the south pole in the Antarctic one can see such familiar constellations as, for instance, Canis Major (with Sirius), Scorpio, Sagittarius, Capricornus, and many others. When observing these constellations in the northern hemisphere of the earth, remember that they are also a constant adornment of the starry skies of the south.

THE MILKY WAY AND THE ZODIAC

The Milky Way is a faintly luminous, irregularly outlined belt stretching across the entire sky. It varies in width from broad sections exceeding 15° across to narrow patches of only a few degrees.

The Milky Way passes through the following constellations: Monoceros, Canis Minor, Orion, Gemini, Taurus, Auriga, Perseus, Camelopardus, Cassiopeia, Andromeda, Cepheus, Lacerta, Cygnus, Vulpecula, Lyra, Sagitta, Aquila, Scutum, Sagittarius, Ophiuchus, Corona Australis, Scorpio, Norma, Lupus, Triangulum Australis, Centaurus, Circinus, Crux, Musca, Carina, Vela, and Puppis.

The patchy structure of the Milky Way is immediately apparent to the eye. It is very inhomogeneous; along with dull, hardly visible portions, there are "star clouds" which are so bright that they may often be confused with ordinary rain clouds. These structural features of the Milky Way are due mainly to two factors: 1) a real nonuniform distribution of stars in the Galaxy, where star clouds may be regarded as a kind of element of structure; 2) the presence of an absorbing medium that imparts to the Milky Way fanciful shapes in the form of dark nebulae diversified in outline and size. To this we need only add that the apparent concentration of stars in the sky in the region of the Milky Way is caused, as we have already pointed out, by the disc-like shape of the Galaxy. If our stellar system were of the structure of a globular cluster and if we were located at its centre, there would be no Milky Way in the sky. The stars would be scattered over the celestial sphere in a rather uniform fashion.

Inside the Milky Way we can note a sort of median line, the so-called galactic equator. On the celestial sphere it

is a great circle inclined to the plane of the celestial equator at an angle of 62°. The celestial equator and the galactic equator intersect in two points located in the constellations Aquila and Monoceros. The two points, 90° distant from the galactic equator, are called the *poles of the Galaxy.* The north pole of the Galaxy lies in the constellation Coma Berenices (Right Ascension: 12h 40m, Declination: +28°), the south pole, in the constellation Sculptor (Right Ascension: 0h 40m, Declination: —28°). When studying the Galaxy it is convenient to use the galactic system of coordinates in which the galactic equator is the basic great circle.

The most convenient time for observing the Milky Way is on the dark nights of August and the first half of September. The patchiness of the Milky Way is particularly evident in the constellation Cygnus. A very prominent feature is the exceedingly bright and dense star cloud in the constellation Scutum. There are also several bright star clouds in the constellation Sagittarius, but they are not so impressive as those in Scutum due to the low position on the horizon.

From Deneb, the Milky Way falls to the horizon in two brilliant streams. This "Great Slit", as it is sometimes called, is due to numerous and comparatively close dark nebulae that block out bright regions of the Milky Way in these spots. In the southern hemisphere of the sky, near The Southern Cross, one can see the famous Coal Sack, a pitch black patch of the Milky Way which seventeenth-century observers considered to be a real "hole in the sky". Actually, it is a dark cloud of cosmic "smoke" that obscures the stellar worlds beyond.

For a detailed picture of the structure of the Milky Way, see the special maps given in the Appendix. Naked-eye observations should be combined with binocular studies of the structural features of the Milky Way. These observations are quite obviously useful, for anyone who simply looks at the Milky Way will see with the unaided eye the complex structure of the Galaxy and the colossal masses of dark cosmic matter that absorbs light.

We conclude our story of the starry sky with a few remarks about the star-like luminaries that occasionally "spoil" the customary patterns of the constellations and may puz-

zle the novice. These are the planets, not all of them, only the brightest.

We exclude Mercury, which constantly hides in the rays of the sun and is never seen here on the starry sky background. Uranus, Neptune and Pluto will never bother anyone in studying the constellations because they are so faint. The same goes for the tiny planets called asteroids. But the four planets, Venus, Mars, Jupiter and Saturn, are among the brightest objects in the sky, and can easily be taken for stars. To avoid such confusion, learn well the twelve constellations of the Zodiac (see p. 61). Add Ophiuchus, which does not belong to the Zodiac, but contains a good portion of the ecliptic.

Venus, Mars, Jupiter and Saturn are observable only in the zodiacal constellations. Secondly, remember that unlike bright stars the planets do not twinkle. True, if planets are viewed just above the horizon and if the atmosphere is not calm, they do twinkle a bit.

Next, each of the above-mentioned planets has a characteristic colour. Venus is a brilliant white, Jupiter is a yellowish-white, Mars is reddish, and Saturn is a drab-yellow. Venus is seen in the western and eastern parts of the sky and appears in the rays of the rising and setting sun (during periods of maximum brilliance) before any of the stars. Mars, Jupiter and Saturn may be seen at any hour of the night.

The distance between the planets and the sun is constantly changing and this means that their apparent brightness varies as well. The brightest of all the planets is Venus; it reaches Mag. —4.8. Mars has a maximum brightness of —1.6, Jupiter, —2.3, Saturn, —0.9. Remember that the brightness of all the planets varies over a broad range; for instance, Mars at its greatest recession from the earth appears as a totally inconspicuous reddish star of the second magnitude.

Finally, the chief peculiarity of the planets, these "wanderers" of space, is their movements among the constellations. If the precise position of a planet is noted on a star map and then observed again in two or three weeks, the shift in position of the planet (with the exception of Saturn) among the stars will become obvious.

To summarize, then, when studying the zodiacal constellations, be ready to meet any one of the bright planets.

Incidentally, you can be prepared for an encounter of a planet in a specific place because Astronomical calendars, which are published every year, and other similar publications (Almanacs, for example) give brief information on the visibility of the planets.

You are now acquainted with the chief sights and wonders of the night sky. True, it is only a first and superficial acquaintance, but if it has excited some interest in the world of outer space and its multifarious kingdom of celestial bodies, you will probably want to continue to study the heavens as an astronomy fan and perhaps make contributions to the science of astronomy. If so, the author will feel his task fulfilled.

APPENDIX I

The Constellations

Nominative case	Position	Genitive case	Designation	Area in sq. degrees	Number of stars brighter than Mag. 6.0
Andromeda	N	Andromedae	And	722	100
Antlia	S	Antliae	Ant	239	20
Apus	S	Apodis	Aps	206	20
Aquarius		Aquarii	Aqr	980	90
Aquila		Aquilae	Aql	652	70
Ara	S	Arae	Ara	237	30
Aries		Arietis	Ari	441	50
Auriga	N	Aurigae	Aur	657	90
Boötes		Boötis	Boö	907	90
Caelum	S	Caeli	Cae	125	10
Camelopardus	N	Camelopardi	Cam	757	50
Cancer		Cancri	Cnc	506	60
Canes Venatici	N	Canum Venaticorum	CVn	465	30
Canis Major		Canis Majoris	CMa	380	80
Canis Minor		Canis Minoris	CMi	183	20
Capricornus		Capricorni	Cap	414	50
Carina	S	Carinae	Car	494	110
Cassiopeia	N	Cassiopeiae	Cas	598	90
Centaurus	S	Centauri	Cen	1,060	150
Cepheus	N	Cephei	Cep	588	60
Cetus		Ceti	Cet	1,230	100
Chamaeleon	S	Chamaeleontis	Cha	132	20
Circinus	S	Circini	Cir	93	20
Columba	S	Columbae	Col	270	40
Coma Berenices		Comae Berenices	Com	386	50
Corona Australis	S	Coronae Australis	CrA	128	25
Corona Borealis		Coronae Borealis	CrB	179	20
Corvus		Corvi	Crv	184	15
Crater		Crateris	Crt	282	20
Crux	S	Crucis	Cru	68	30

Nominative case	Position	Genitive case	Designation	Area in sq. degrees	Number of stars brighter than Mag. 6.0
Cygnus	N	Cygni	Cyg	804	150
Delphinus		Delphini	Del	189	30
Dorado	S	Doradus	Dor	179	20
Draco	N	Draconis	Dra	1,083	80
Equuleus		Equulei	Equ	72	10
Eridanus		Eridani	Eri	1,138	100
Fornax		Fornacis	For	398	35
Gemini		Geminorum	Gem	514	70
Grus	S	Gruis	Gru	366	30
Hercules		Herculis	Her	1,225	140
Horologium	S	Horologii	Hor	249	20
Hydra		Hydrae	Hya	1,300	130
Hydrus	S	Hydri	Hyi	243	20
Indus	S	Indi	Ind	294	20
Lacerta	N	Lacertae	Lac	201	35
Leo		Leonis	Leo	947	70
Leo Minor		Leonis Minoris	LMi	232	20
Lepus		Leporis	Lep	290	40
Libra		Librae	Lib	538	50
Lupus	S	Lupi	Lup	334	70
Lynx	N	Lyncis	Lyn	545	60
Lyra	N	Lyrae	Lyr	286	45
Mensa	S	Mensae	Men	153	15
Microscopium	S	Microscopii	Mic	210	20
Monoceros		Monocerotis	Mon	482	85
Musca	S	Muscae	Mus	138	30
Norma	S	Normae	Nor	165	20
Octans	S	Octantis	Oct	291	35
Ophiuchus		Ophiuchi	Oph	948	100
Orion		Orionis	Ori	594	120
Pavo	S	Pavonis	Pav	378	45
Pegasus		Pegasi	Peg	1,121	100
Perseus	N	Persei	Per	615	90
Phoenix	S	Phoenicis	Phe	469	40
Pictor	S	Pictoris	Pic	247	30

Nominative case	Position	Genitive case	Designation	Area in sq. degrees	Number of stars brighter than Mag 6.0
Pisces		Piscium	Psc	889	75
Piscis Australis		Piscis Australis	PsA	245	25
Puppis		Puppis	Pup	673	140
Pyxis		Pyxidis	Pyx	221	25
Reticulum	S	Reticuli	Ret	114	15
Sagitta		Sagittae	Sge	80	20
Sagittarius		Sagittarii	Sgr	867	115
Scorpio		Scorpii	Sco	497	100
Sculptor		Sculptoris	Scl	475	30
Scutum		Scuti	Sct	109	20
Serpens		Serpentis	Ser	637	60
Sextans		Sextantis	Sex	314	25
Taurus		Tauri	Tau	797	125
Telescopium	S	Telescopii	Tel	252	30
Triangulum		Trianguli	Tri	132	15
Triangulum Australe	S	Trianguli Australis	TrA	110	20
Tucana	S	Tucanae	Tuc	295	25
Ursa Major	N	Ursae Majoris	UMa	1,280	125
Ursa Minor	N	Ursae Minoris	UMi	256	20
Vela	S	Velorum	Vel	500	110
Virgo		Virginis	Vir	1,290	95
Volans	S	Volantis	Vol	141	20
Vulpecula		Vulpeculae	Vul	268	45

APPENDIX II

The Greek Alphabet

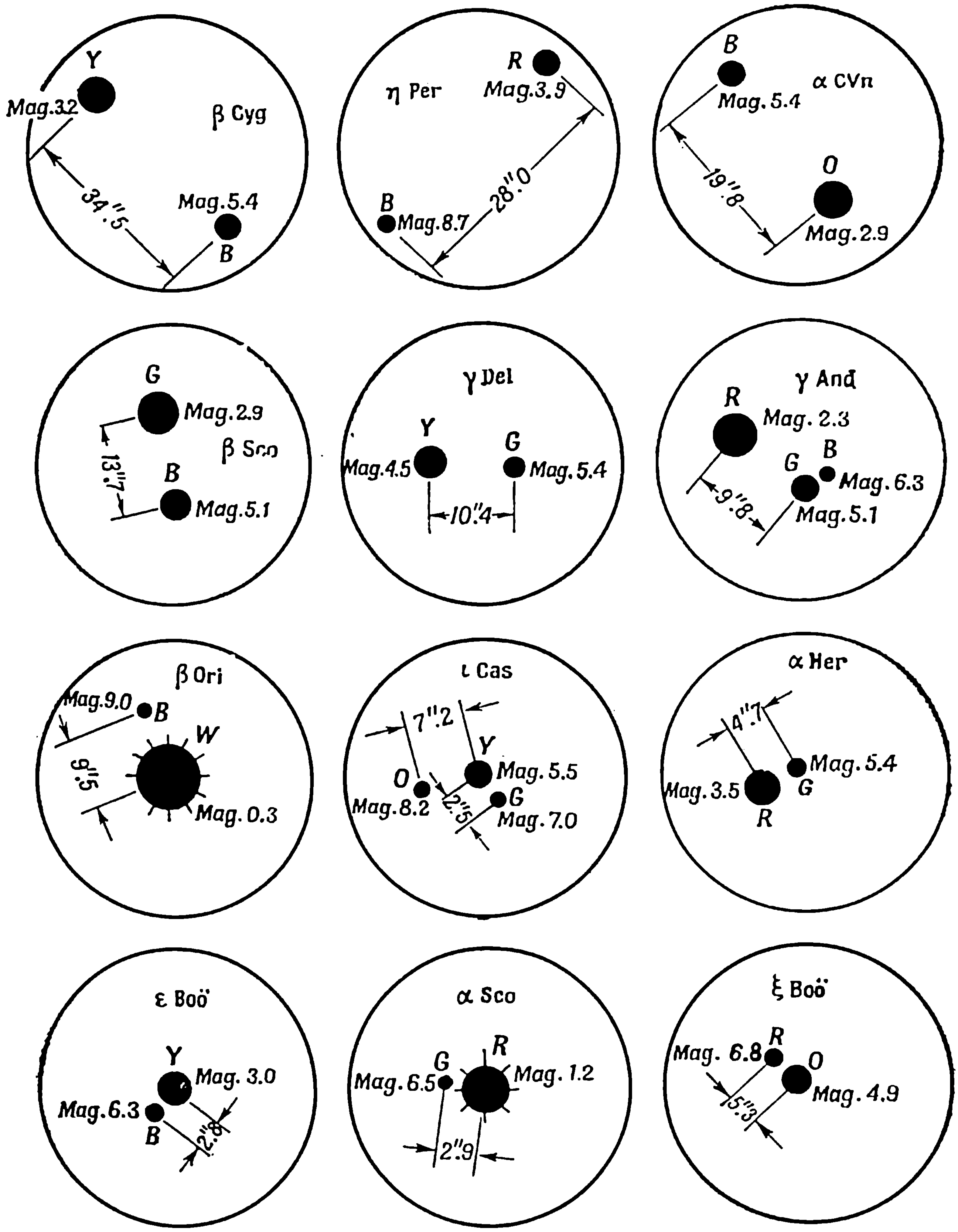
Α,	α	alpha	Ζ,	ζ	zeta	Λ,	λ	lambda
Β,	β	beta	Η,	η	eta	Μ,	μ	mu
Γ,	γ	gamma	Θ,	ϑ, θ	theta	Ν,	ν	nu
Δ,	δ	delta	Ι,	ι	iota	Ξ,	ξ	xi
Ε,	ε	epsilon	Κ,	κ	kappa	Ο,	ο	omicron

Π,	π	pi	Τ,	τ	tau	Χ,	χ	chi
Ρ,	ρ	rho	Υ,	υ	upsilon	Ψ,	ψ	psi
Σ,	σ, ς	sigma	Φ,	φ	phi	Ω,	ω	omega

APPENDIX III

Some Bright Double Stars with Sharply Contrasting Colours
(see diagrams at the back of the book)

Star	A	B	P	Colour
	(Mag.)	(Mag.)		
γ And	2.3	5.1	10″	Orange and blue
α CVn	2.9	5.4	20	Yellow and violet
β Cyg	3.2	5.4	35	Yellow and blue
ε Boö	2.7	5.1	3	Yellow and green
α Her	3.5	5.4	5	Yellow and blue
α Sco	1.2	6.5	3	Orange and green
γ Her	4.5	5.5	11	Red and emerald
ε Hya	3.8	5.0	0.3	Yellow and blue
κ Gem	3.7	8.5	7	Orange and blue
η Per	3.9	8.5	28	Yellow and blue
η Cas	3.7	7.4	9	Yellow and purple
δ Her	3.2	8.1	10	White and violet
ι Cnc	4.2	6.6	31	Yellow and blue
β Sco	2.9	5.1	14	White and greenish-yellow

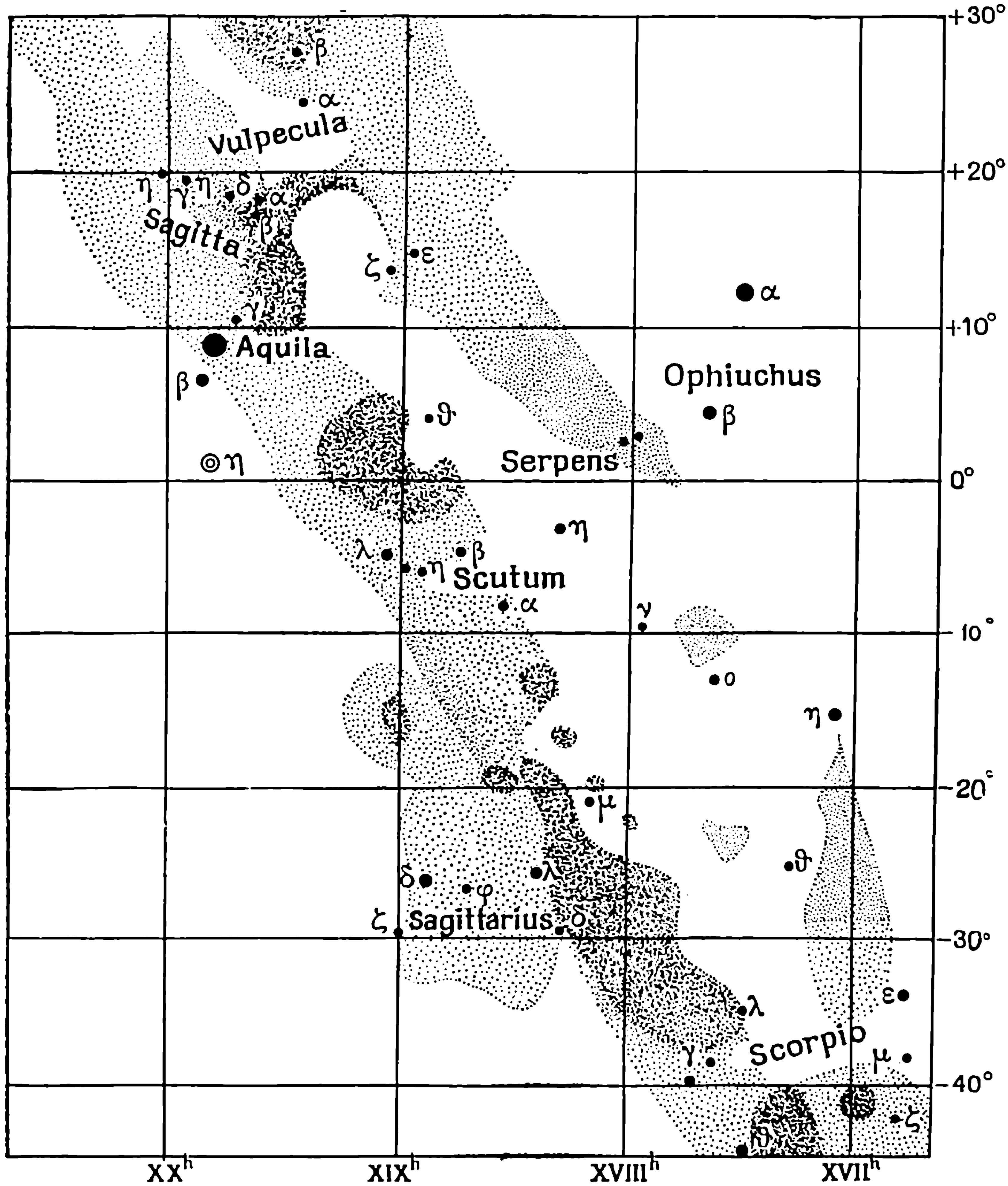


Colours: *Y-yellow* *R-red*
B-blue *W-white*
G-green *O-orange*

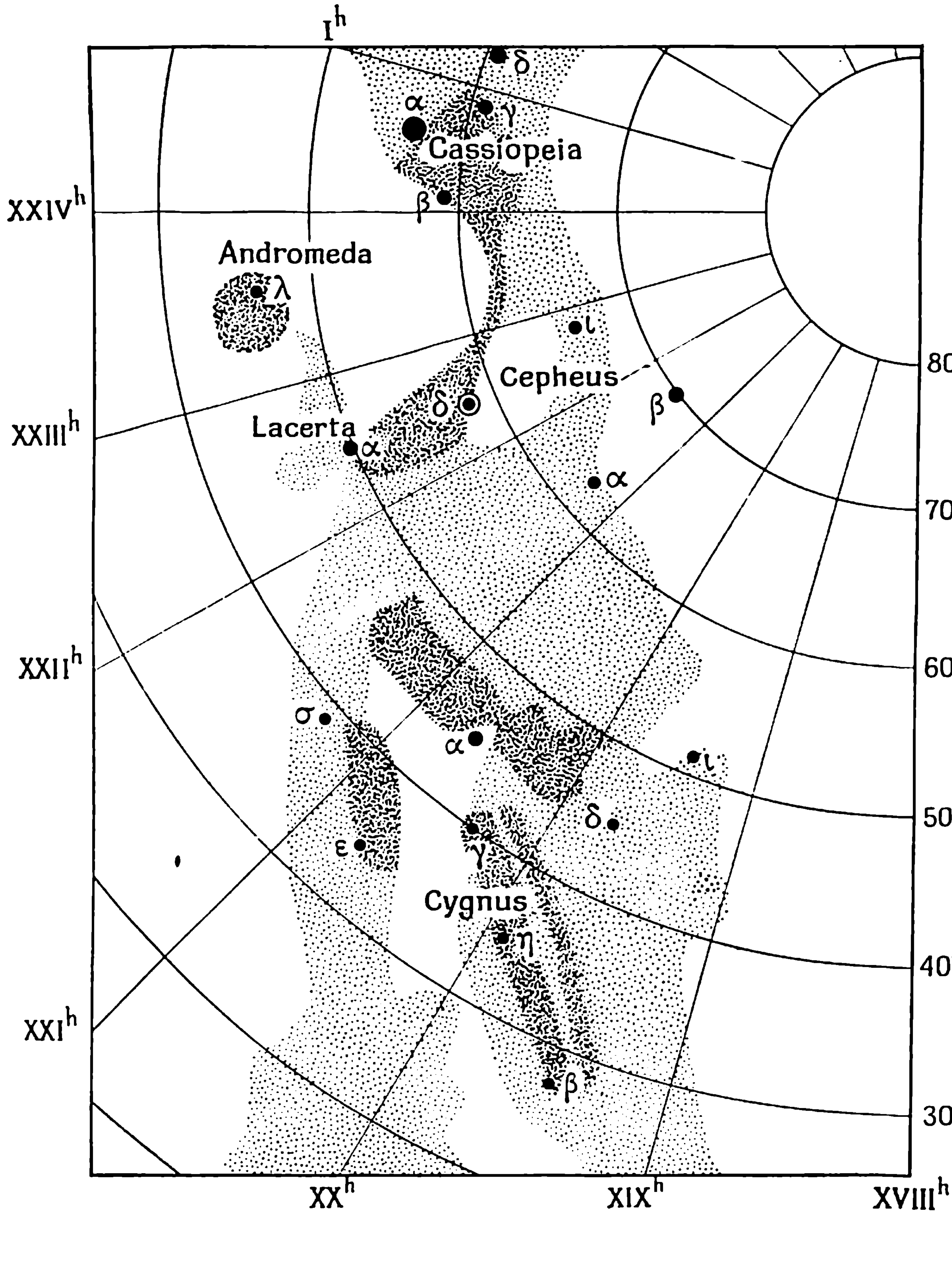
Position and Colours of Certain Double Stars

APPENDIX IV

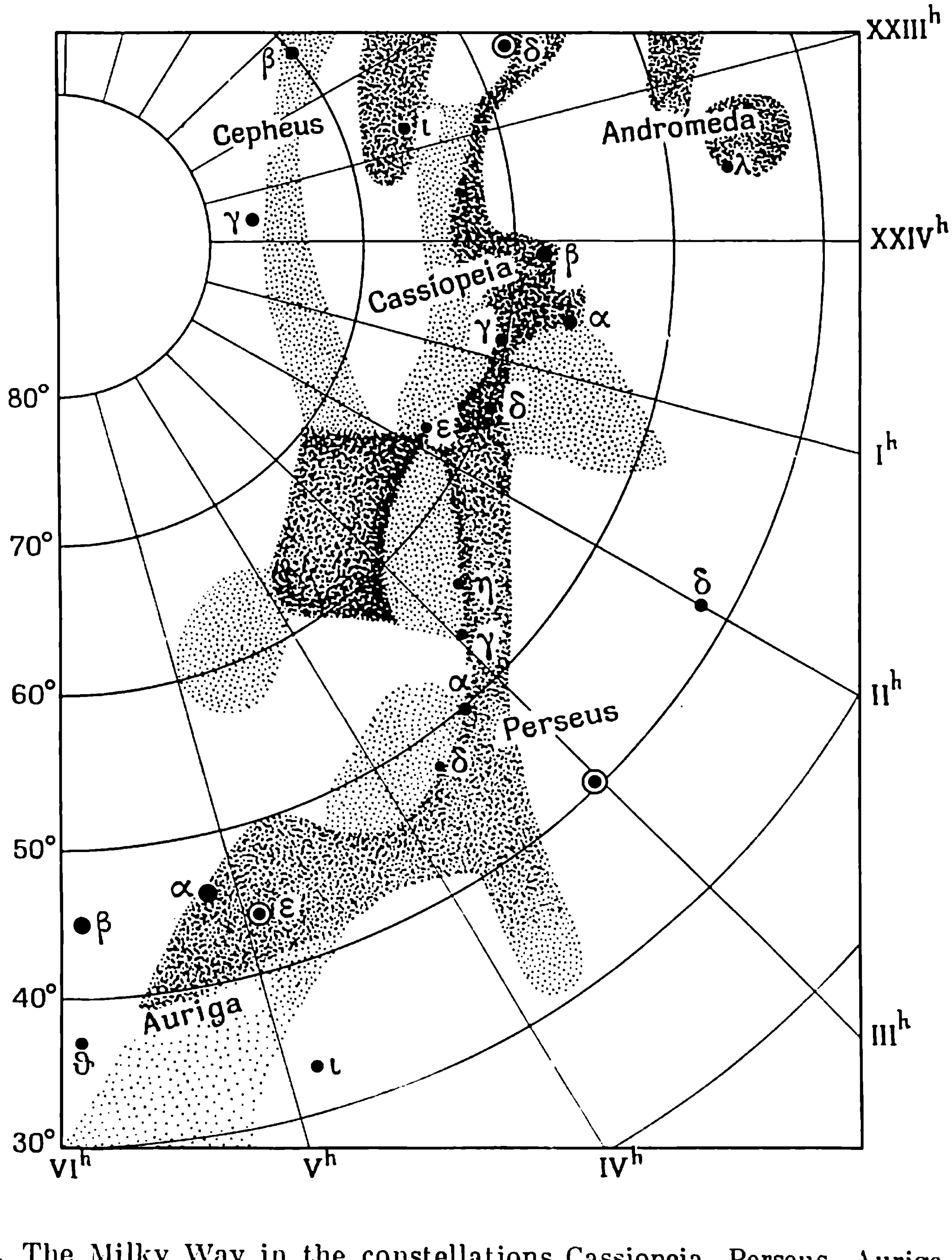
Schematic Charts of the Milky Way



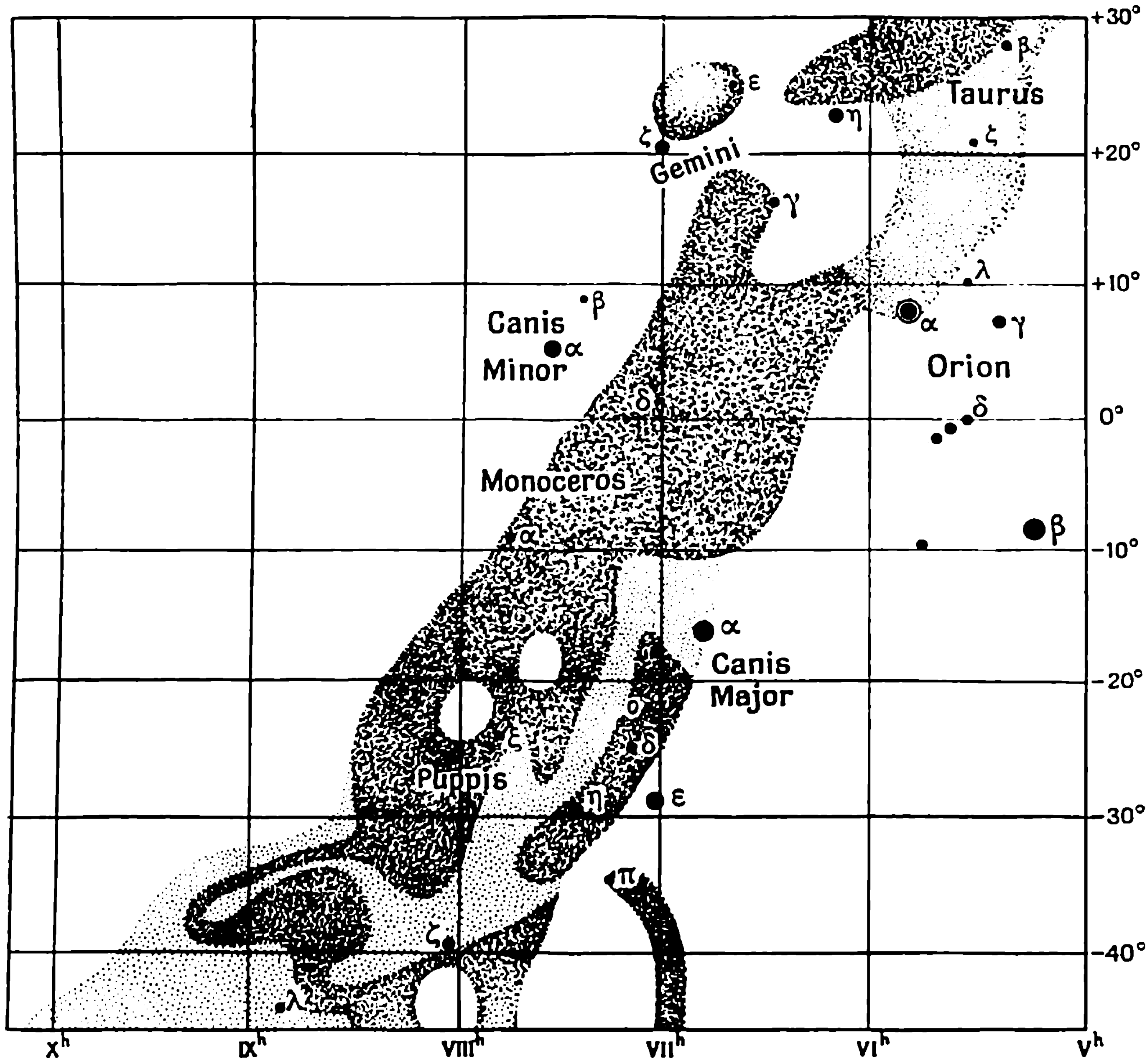
1. The Milky Way in the constellations Scorpio, Sagittarius, Scutum, Aquila, Vulpecula.



2. The Milky Way in the constellations Cygnus, Lacerta, Cepheus, Cassiopeia.



3. The Milky Way in the constellations Cassiopeia, Perseus, Auriga.



4. The Milky Way in the constellations Taurus, Monoceros, Puppis.

APPENDIX V

Maps of the Night Sky
(see coloured inserts)

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